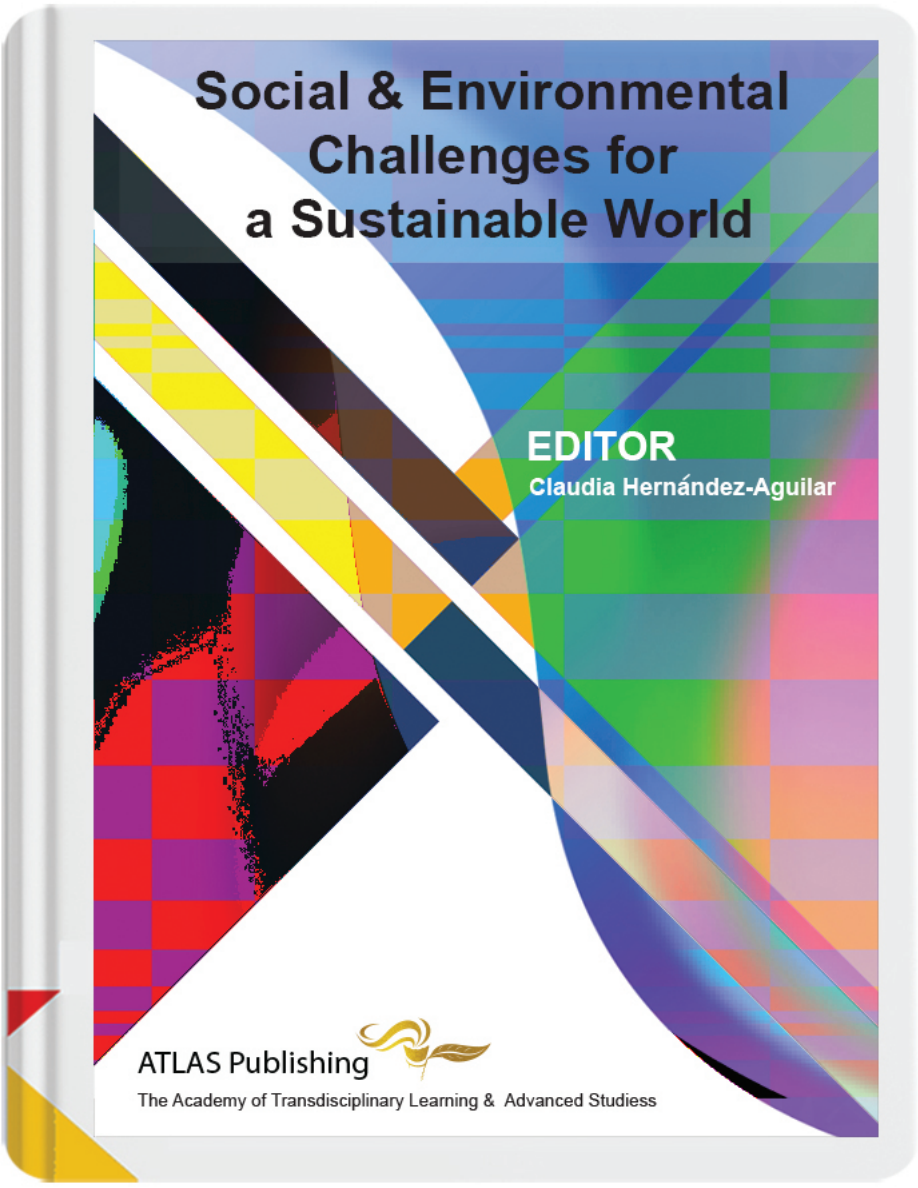
Social & Environmental Challenges for a Sustainable World
EDITOR
Claudia Hernández-Aguilar
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Editor
Claudia Hernández-Aguilar

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Claudia Hernández-Aguilar
National Polytechnic Institute
Mexico

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Preface

In the present Transdisciplinary Journal of Engineering & Science (TJES) (ISSN 1949-0569), 50 years after the United Nations Conference on Human Environment (1972), the first to express the environment as a central theme of concern at international level, is pleased to join in commemorating and specially to communicate contributions of some authors from various countries, towards the achievement of this great global goal of sustainable development. As is well known, due to the Covid-19 pandemic, the sustainable development indicator did not improve in most of the countries, and some even saw a decrease and a failure to meet the 17 programmed goals, facing challenges for their achievement. Thus, the transdisciplinary perspective, based on the formation and transformation of the research subject, as mentioned in its definition by Dr. Nicolescu Basarab, a "Generalized transgression that opens an unlimited space of freedom, tolerance, knowledge and love", remains a hope for the progress of humanity and sustainable development. These are the yearnings of mankind in history and that today, in the global context we are living in, it is essential to take into consideration, because it leads to changes in individuals in their way of being, looking, thinking, feeling, perceiving, acting, living, coexisting, co-constructing and not destroying, and valuing what we are and what we have. The change of attitude, consciousness and thinking could be indispensable elements for development, evolution, and sustainability.

Dr. Bronfenbrenner proposed the ecosystemic model to describe the external influences on the development of the individual. It could be appreciated in this evolution of consciousness, now in an inverse way; the influence that everyone can have towards his environment, near and far, from his ontosystem, towards the micro, meso, exo, macro, chrono and global system, and be a detonating element of changes. We are co-responsible along with governments and decision makers in our countries to make the change. The self-observation of which Edgar Morin has spoken as the first task is basic in research, because we would expect to provoke change in each one of us and thus in others. The path of evolution and not involution as sometimes seems to happen in the world.

Thus, we thank Dr. Atila Ertas for the invitation he kindly extended to me to participate as Editor of this special issue of the Journal (TJES) and the book entitled: Special Issue: "Social & Environmental Challenges for a Sustainable World". Addressing the following topics 1). unstructured global problems such as health (physical, mental, spiritual), disasters, poverty and hunger, water and food crisis, environmental crises, climate change, sustainability, global economy, energy problems, problem of conscience, research on contemporary issues, interdisciplinary and transdisciplinary educational program.

For this purpose, colleagues who were interested in sharing proposals and results of their research were invited to participate. A total of 13 papers were received, including 8 full-length articles and 5 short articles. We thank the participants from Indonesia, Canada, Portugal, China, Spain, India, France, Pakistan, and Mexico for each of the contributions.

Convinced that the scientific and academic community plays an important role as they could propose educational interventions in the different communities, localities, nations, regions; that finally lead to paths of peace among men and within man himself, allowing him to continue generating sustainable proposals to co-construct a better world.

Claudia Hernández Aguilar

Editor

About the Editor

Dra. C. Hernandez-Aguilar is a professor-researcher of the National Polytechnic Institute, within the Graduate Program in Systems Engineering of ESIME-Zacatenco. Member of the Mexican Academy of Sciences and the National System of Researchers (México). International distinction as member of the Editorial Committee of the journal: International Agrophysics (period:2012-present). Coordinator of the graduate programs in systems engineering (period 2012-2017). Creator and leader of the research group on Biophysical Systems for Agriculture, Food and Medicine with a Transdisciplinary approach. Main contributions related to methods for improvement and quality evaluation of agricultural seeds and food. Among other methods: laser radiation, electromagnetic field (fixed and variable), ultraviolet radiation (A-B-C), infrared, LED diodes, ozone, natural. In addition, the researcher proposes food products using nutraceutical: turmeric bread, moringa, lentil sprouts, etc. Working to Create a culture for its consumption to improve the health of the population based on a low glycemic index diet. Concerned and occupied in improving the quality of life of society. Trainer of researchers in the last 15 years, making a call to conscience, to rescue a human attitude in the research process and the impact obtained from it. Motto: Transform yourself, to transform your world.

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CHAPTER 1

Near Infrared Technology in Agricultural Sustainability: Rapid Prediction of Nitrogen Content from Organic Fertilizer

Devianti, Sufardi, Mustaqimah, Agus Arip Munawar

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In order to support agricultural sustainability, rapid and precise method needs to be applied for resources efficiency. Presented study employs the near infrared reflectance (NIRS) as a rapid and effective sensing technology in detecting and determining quality parameter of organic fertilizer in form of nitrogen content (N). a total of 10 organic fertilizers were used as samples made from agricultural waste. Near infrared spectra data were acquired and measured as absorbance for all samples in wavenumbers range 5,000 – 11,000 cm-1. On the other hand, actual N content was measured by means of standard laboratory procedures. Spectra data were corrected using de-trending second order (DT-2), standard normal variate (SNV) and combination of them (SNV+DT). Moreover, prediction models for N content determination were developed using principal component regression (PCR) followed by leverage cross validation. The results showed that N content can be predicted rapidly without involving chemical materials with maximum coefficient of determination are 0.98 for calibration and 0.95 for validation phase respectively. Spectra correction was highly affected the prediction performance and can improve prediction accuracy. The combination spectra correction SNV+DT increase the prediction up to 0.95 from previously 0.90. Therefore, It would be better if the spectra data were corrected and enhanced prior to prediction modelling to improve the performance. Based on obtained results, it may conclude that sensing technology based on NIRS can be applied to support agriculture sustainability as a rapid and effective method for N determination of organic fertilizers.

Keywords: Agriculture, NIRS, organic, resources, soil.

1.1 Introduction

Agricultural sustainability development is essential in the most of developing countries improve land production and conservation of natural resources. The development agricultural sustainability practices and increase of production in farming system is inseparable from the interaction factors of each component involved in it. Inputs given to the farming

system can come from outside or from the farming system through recycling of nutrients from agricultural waste in the form of compost products or animal feed. Recycling of nutrients in the farming system is a key factor in maintaining its sustainability (Hong et al., 2019; Yu et al., 2018). The problem faced in treating agricultural waste is the low level of farmers' knowledge of the benefits of waste. Different community perceptions of the existence of the waste resulted in slow handling of the waste. Some people are of the opinion that managing waste is a work that is not important to do, does not provide benefits, and it is time consuming. The public perception must be changed to see the amount of waste that continues to grow every year. Addition of waste that is not in accordance with the level of management has a very bad impact on the sustainability of agriculture in Indonesia (Agus Arip Munawar, Yunus, Devianti, & Satriyo, 2020; Yunus, Devianti, Satriyo, & Munawar, 2019).

Agricultural sustainable management receives considerable support and acceptance within agriculture prevailing, depending on some environmental concerns. Utilization of agricultural waste can help farmers overcome the problem of shortages for organic fertilizer. Straw produced from harvesting can be dried and stored to be used as material for making organic fertilizer. Horticultural crops such as vegetables are also very well used for making compost. That the most crop production is rice. Rice production of 19,134 quintals with a planting area of 3,045 hectares and a harvesting area of 2,511 hectares produces 4-5 tons of hay/ha. Rice straw is one alternative to offset the shortage of farmers for animal feed purposes (Devianti, Sufardi, Zulfahrizal, & Munawar, 2019; Devianti, Yusmanizar, Syakur, Munawar, & Yunus, 2021)

In general, the condition of agricultural land in Indonesia has experienced a decline in fertility and soil damage and consequently, has a decline in agricultural crops productivity, especially intensification of paddy fields. The causes include: a) imbalance of nutrient content in the soil; b) drainage and nutrient deficits; c) decrease in soil organic matter content; d) silting of the flow tread layer; e) pollution by agrochemicals or waste; f) decrease in population and microbial activity. As a result of unwise management of nutrients, most of the paddy fields are indicated to have very low levels of organic matter (C-organic <2%). About 65% of the 7.9 million ha of paddy fields in Indonesia have low to very low organic matter content (C- organic <2%), around 17% have low total soil P levels and around 12% have low total K levels. In the intensification of paddy fields, an increasingly shallow layer of tillage was encountered so that the roots of rice plants could not develop properly (Meer, 2018; Wan et al., 2019; Yu et al., 2018). The sustainable agriculture practices can be considered to maintain foods and agricultural production without causing environmental pollutions.

The use of fertilizers in dry land generally uses inadequate doses, so it is suspected that nutrient depletion occurs. In addition, the use of compost or return the rest of the harvest to agricultural land is almost not done. Especially for dry land in sloped areas, not yet implementing ideal soil conservation measures, resulting in erosion and high surface runoff. The impact of erosion causes nutrient content and organic material to move to lower land. To reduce the deterioration of soil fertility and increase the productivity of sustainable yields it is necessary to use adequate compost fertilizer in quantity, quality and continuity. Plant requires compost with different nutrients, therefore farmers must provide compost with nutrients according to the needs of the plant (Hong et al., 2019; Sun, Zhang, Sun, Sun, & Cen, 2018). The problem that is found at this time is not the amount of compost sold in the market and the nutrient content that has not been included

in the compost, so that the farmers are not informed about the nutrient content that will be given to plants. Nutrient content in compost is usually known through laboratory testing, but if a laboratory test is carried out nutrient tests make us spend a lot of money and take a long time. With the sophistication of the modern era there is now a tool to make it easier for us to predict the content that is in both solid and liquid materials, namely near infrared reflectance spectroscopy (NIRS) technology (Baveye & Laba, 2015; Soriano-Disla, Janik, & McLaughlin, 2018). It is recognized and developed as a non-destructive method, can analyze at high speed, does not cause pollution, simple sample preparations and does not require any chemical materials.

In the practices and applications of near infrared reflectance spectroscopy, multivariate analysis plays an important role in analysing overlapping spectral data. They were obtained from the near infrared spectrophotometers not only contain sample information but also contain background and noises (Deng, Wang, Zhong, & Yu, 2018; Pasquini, 2018). Therefore, it is necessary to pre-process before building the calibration model. Pre-processing is a step of data transformation to improve the spectrum that is not good due to the blending of light when the acquisition of near infrared data, noise, interference from the outer circle and other problems that cause the information contained in the spectrum to be difficult to analyze.

Numerous studies have been reported in related to the application of NIRS technology in many fields, especially in agriculture like fruit quality evaluation (Jha et al., 2012; Agus Arip Munawar, von Hörsten, Wegener, Pawelzik, & Mörlein, 2016; Nagle, Mahayothee, Rungpichayapichet, Janjai, & Müller, 2010), animal feed quality parameters prediction (Samadi, Wajizah, & Munawar, 2018), cocoa and coffee quality in intact green bean form (León-Roque, Abderrahim, Nuñez-Alejos, Arribas, & Condezo-Hoyos, 2016; Sunoj, Igathinathane, & Visvanathan, 2016; Teye, Huang, Dai, & Chen, 2013), soil quality attributes prediction and other biological material properties (Johnson et al., 2019; Shi, Wang, Chen, & Wu, 2016). Thus, the main purpose of this present study is to apply the NIRS technology in determining N content of organic fertilizers made from recycled agricultural waste. The prediction models were established using PCR regression approach with different spectra correction algorithms models (Pasquini, 2018).

1.2 Materials and Methods

Spectra Data

The near infrared spectrum for all compost samples were acquired and obtained using portable near infrared spectroscopy instruments (PSD NIRS, iptek i16) with workflow configurations built using an integrated software namely Thermo Integration®. Workflow is made to acquire absorbance spectrum and scan samples 27 times (A A Munawar, Yunus, Devianti, & Satriyo, 2021; Agus Arip Munawar, Devianti, Satriyo, Syahrul, & Yunus, 2019). Each sample is measured in three different points, then averaging the results and storing those spectral data in two file formats.

Samples

Organic fertilizers were made from un-used agricultural waste with detailed compositions is described in Table 1.

Table 1: Composting materials used as fertilizer samples

Compost materials	Percentage
Straw + cow manure	50%+25%
Straw + goat manure	50%+25%
Straw + chicken manure	50%+25%
Straw + corn + cow manure	50%+25%+25%
Straw + corn + goat manure	50%+25%+25%
Straw + corn + chicken manure	50%+25%+25%
Corn + cow manure	50%+25%
Corn + goat manure	50%+25%
Corn + chicken manure	50%+25%

Actual Nitrogen Measurement

After obtaining spectra data, all samples were taken to the lab for actual N content measurement. It was conducted using Kjeldahl method and measured in triplicate, then averaged. The actual nitrogen content was used as a verification data in calibration and validation phases (Biancolillo, Firmani, Bucci, Magrì, & Marini, 2019; Hong et al., 2018).

Spectra Data Corrections

Before being used for data analysis (building prediction models), the NIR spectrum for all compost samples was corrected. This aims of this step is to eliminate various kinds of "noises" in the compost sample spectrum so that the prediction results are more accurate and robust (Arendse, Fawole, Magwaza, & Opara, 2018; Pasquini, 2018). The methods used in this spectra corrections are: de-trending second order (DT-2), standard normal variate (SNV), and combination of them (SNV+DT) (Agus Arip Munawar, Devianti, Satriyo, & Yunus, 2019).

Prediction Models

The nitrogen content in organic fertilizer were predicted based on NIR spectral data (raw and corrected) through calibration process and followed by leverage cross validation. Prediction models were built by regressing the NIR spectrum (variable X) with the actual N content (variable Y) from the measurement results in the laboratory (Comino, Aranda, García-Ruiz, Ayora-Cañada, & Domínguez-Vidal, 2018; Pasquini, 2018). The calibration method that were used in this phase is the principal component regression (PCR). All data analysis including spectra corrections and prediction models development were carried out using The Unscrambler X 10.3 Software (CAMO Oslo, Norway) with network client licensed. Justification of the model (accuracy and robustness) is evaluated based on statistical parameters, namely: correlation coefficient (r) or coefficient of determina-

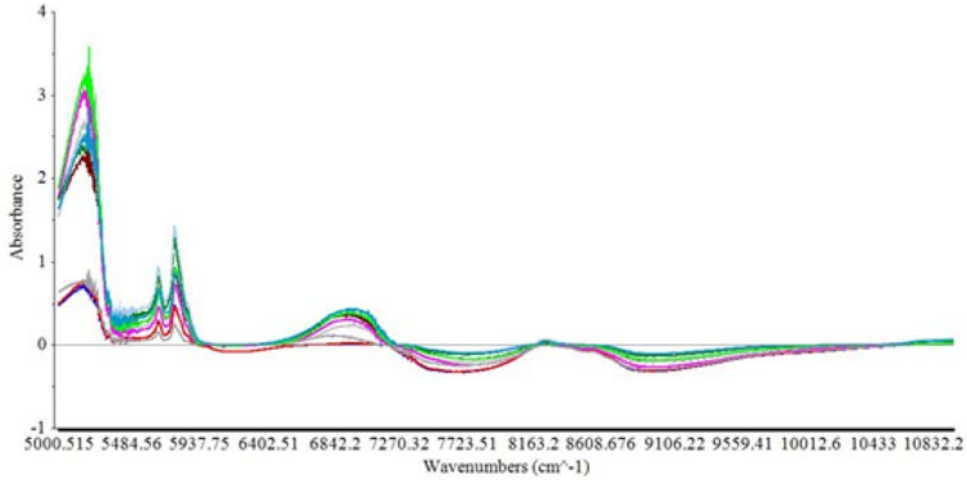

Figure 1.1: *Spectra feature of organic fertilizer samples in NIR region.*

tion (R2) between the prediction results and actual measurement and ratio prediction to deviation (RPD) (Pasquini, 2018).

1.3 Results and Discussion

In general, materials that are subjected to near infrared spectroscopy radiation with presented wavenumber received energy that triggers vibrations in the OH, NH, and CH atomic bonding groups which are the main components of the formation of organic compounds and as a result of molecular bond interactions can indicate the fertilizer chemical content and nutrition.

Some of the energy were absorbed and some will be reflected. Energy that is emitted into organic material, around 4% were reflected back to the outer surface and around 96% were entered the material and then experience absorption, reflection, diffusion and the transmission of light. Radiation on the sample will occur three radiation phenomena, namely absorbed, transmitted, and reflected. In this study the acquisition process uses a wavenumbers range from 5000 to 11000 cm-1. The spectra feature of the organic fertilizer made from the agricultural waste is presented in Figure 1.1.

As shown in Fig.1, the raw spectrum appeared still tenuous the presence of noise at the time of measurement using near infrared spectroscopy. Then it is necessary to perform spectra correction in order to reduce the noise and error that occurs in the generated NIRS waves. Principal component regression (PCR) regression method is a method with a working principle that is the reduction of variables using the principal component. The advantage of this type of regression is the reduced number of predictor variables used for calibration than the number of original variables. The results of the construction of the calibration model using the PCR method produce a model in form of unsb extension files. The PCR method works in conjunction with a black box system where the workings occur within the software. Prediction performance of N content using raw untreated spectra data is presented in Figure 1.2.

The prediction results of raw spectra data for N content prediction using NIRS can be seen that there are quite close to the actual N content measurement with R2 = 0.89 in calibration. Meanwhile, during validation, the R2 is 0.48. In brief, the determination coefficient refers to how large data can be predicted accurately using near infrared method. The higher coefficient determination the better. The determination coefficient 0.89 means 89% of all presented data of N content can be predicted by NIRS. There are some values are different from the results of laboratory tests. The difference between the laboratory test with the NIRS prediction with the standard normal variate is 0.31%, while with the L3 sample code the difference is 1.77%. The accuracy of N content prediction on compost can be evaluated with statistical parameters such as, correlation coefficient (r), coefficient of determination (R2), root mean square error (RMSE), ratio prediction to deviation (RPD) Index, and number of latent variables (LV). When the models were developed using corrected spectra data like DT-2 and SNV, the prediction performance becomes better than raw un-corrected spectral data as shown in Figure 1.3 and Figure 1.4 respectively.

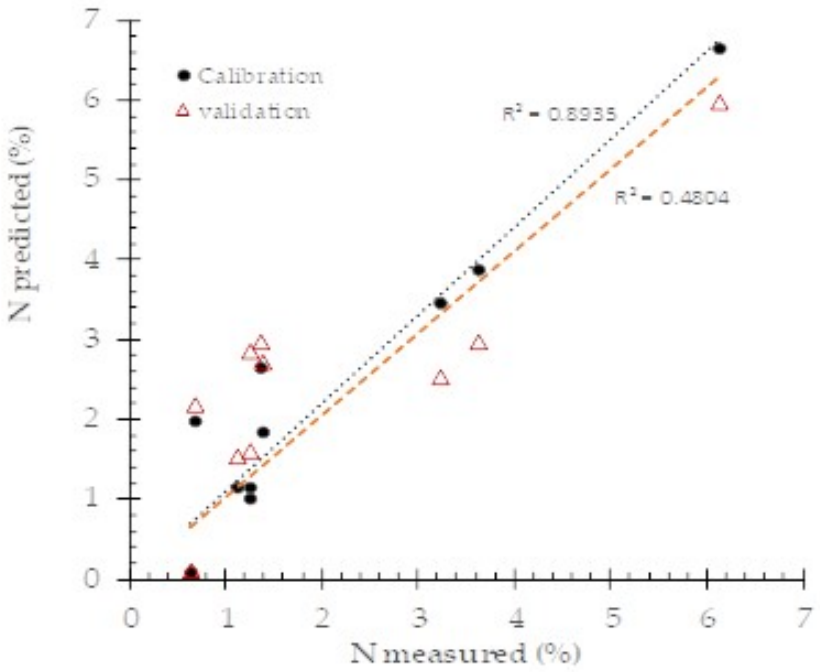

Figure 1.2: *The N content prediction performance using raw spectra data.*

The prediction performance was improved when the model is constructed using corrected spectral data. As shown in Figure 1.3 above, the coefficient of determination is increase to 0.95 in calibration and 0.66 in validation phase respectively. It is obvious that spectra correction is necessary to be performed in order to achieve good prediction results. It also happened when the model is developed using the SNV spectra data.

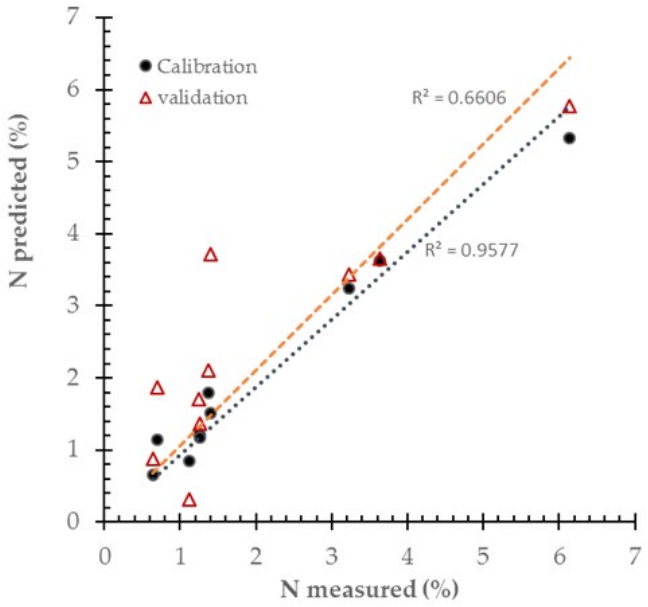

Figure 1.3: *The N content prediction performance using DT-2 spectra data.*

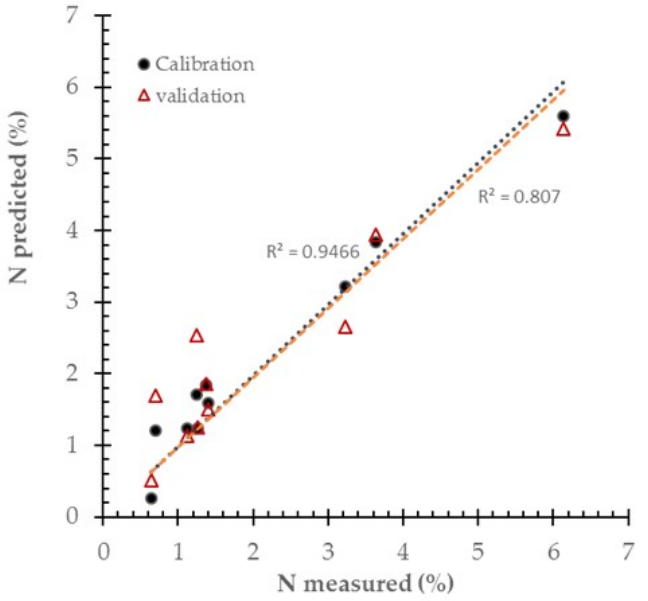

Figure 1.4: *The N content prediction performance using SNV spectra data.*

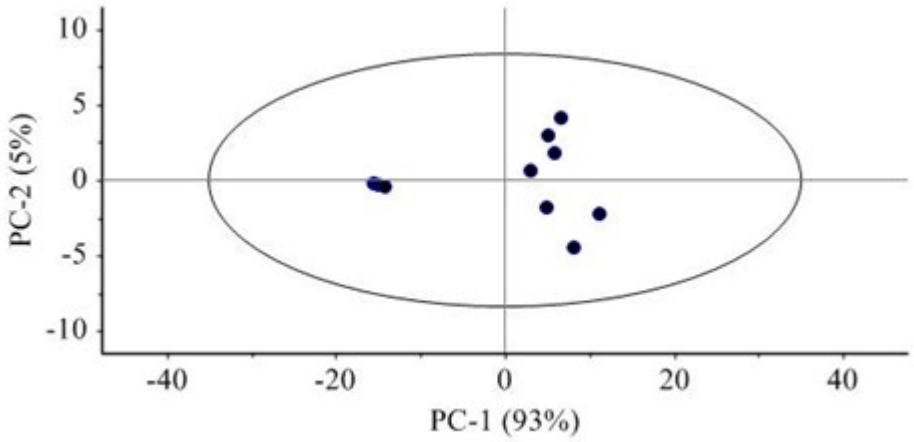

Figure 1.5: *The PCA and Hotelling t^2 ellipse to detect outlier data in raw spectrum.*

The multivariate calibration technique begins with PCA then continues with a regression between the new main components and the response. When predictive variables are not interconnected, this technique is useless. The reduced variable in this case is a prediction variable using the main component (principal component, PC) derived from the Principal component analysis (PCA) grouping method compared to the original variable. This respective method also can be used to detect outlier data on the dataset in combination with Hotelling t2 ellipse as shown in Figure 1.5.

The advantage of this type of regression is the reduced number of predictor variables used for calibration rather than the number of original variables. However, PCR only considers the correlation of predicted variables with the main component (PC) without regard to the strength of the relationship with the response variable. Principal component regression (PCR) is a multivariate calibration method for analyzing statistics of multiple variables that can be used for the purpose of reducing a number of original variables to new orthogonal variables and not reducing and still maintaining a large total diversity of original variables. Thus, calibration regression can be built using the principal component regression method.

It was also mentioned that three main factors were taken into account in the NIR spectroscopy test sample technique, namely particle size, moisture content, and temperature of the material being tested. Furthermore, diffuse reflectance and transmittance of NIR spectra is the result of a condition of the combination of the instrument and the sample or material used, namely the geometry or shape of the instrument, the size of the material being tested (in the form of particles or point of testing), form and distribution of materials when testing and others. Prediction performance was more even better when two spectra correction methods are combined as shown in Figure 1.6.

After the calibration regression model is obtained, a validation step is carried out using the rest of the data. The different sample data is entered into the calibration regression,

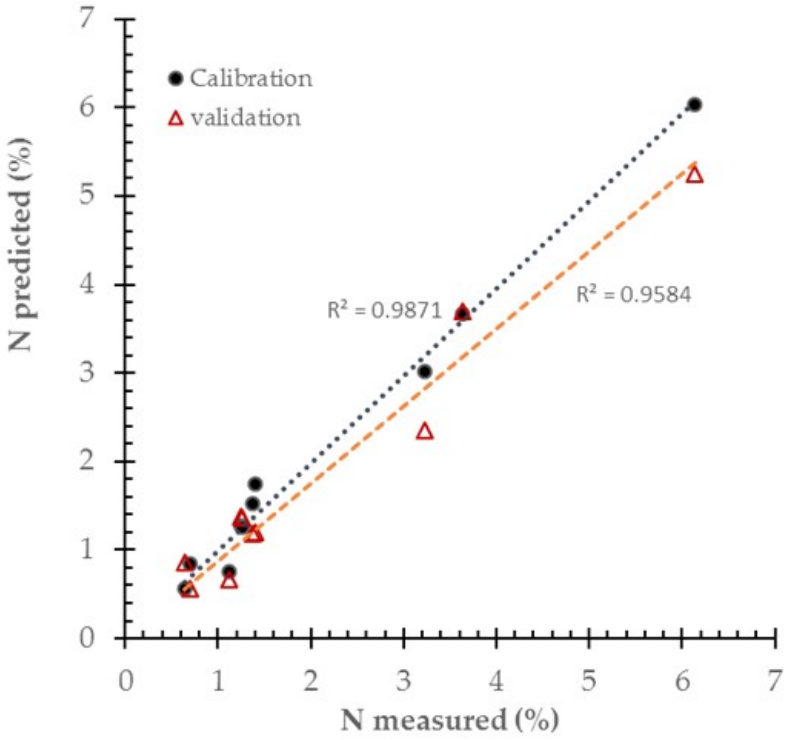

Figure 1.6: *The N content prediction performance using SNV+DT spectra data.*

so that the composition of physical data is obtained. Validation aims to test the accuracy of estimation of chemical composition with calibration regression that has been built. Near infrared which affects the material has little energy and only penetrates about one millimetre of the surface of the material, depending on the composition of the material. If the light is scattered, the spectrum still contains information, for example the absorption of the surface of the material but distortion occurs at the peak of the wave. Variations in the size and temperature of sample particles affect the spread of near infrared radiation as they pass through the sample. Large particles cannot spread near infrared radiation as much as small particles. The more radiation absorbed, the higher the absorbance value will be and the greater the wavelength absorbed. When near infrared radiation hits a solid sample, part of the radiation will be reflected (specular reflectance) from the sample surface. If radiation enters a sample which has a thickness of around 2 mm it will be absorbed. Radiation that is not absorbed can be transmitted through samples or reflected.

The near infrared reflectance spectroscopy is based on the electromagnetic energy located at a wavelength of 780 - 2500 nm or in wavenumbers 4,000 - 12,500 cm-1 and contains more complex information structures because of the combination of bonding patterns. The recording region of the NIRS electromagnetic wave is a response from the bonding of O-H, C-H, C-O and N-H molecules. 10 This bond causes changes in vibrational energy when irradiated by NIRS frequencies, like stretching and bending vibrations.

Based on obtained results, it showed that N content can be predicted rapidly and effectively without involving chemical materials with maximum coefficient of determination are 0.98 for calibration and 0.95 for validation phase respectively. It may conclude that NIRS technology can be applied as a rapid and effective method for N determination of organic fertilizers made from agricultural waste.

1.4 Conclusions

Recycling of nutrients in the farming system is one of main factors in maintaining agricultural sustainability. Organic waste can be benefited and transformed onto organic fertilizers. The chemical quality parameters of these fertilizers can be determined rapidly using near infrared technology with easy sample preparations and without causing environmental pollutions. The prediction performance of the predicted models of Nitrogen content is achieved when the NIRS model is established by means of combined spectral data with maximum determination coefficient 0.98 in calibration and 0.95 in validation. Based on obtained results, it may conclude that sensing technology based on NIRS can be applied to support agriculture sustainability as a rapid and effective method for N determination of organic fertilizers.

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About the Authors

Devianti completed doctoral study in Padjadjaran University, Bandung in the field of Soil and Water Conservation. Research interest related to Soil and Water Engineering, Precision Agriculture and GIS in Sustainable agriculture. https://fsd.unsyiah.ac.id/devianti/

Sufardi served as the Head of Soil Chemistry Laboratory till 2008 and Laboratory of Soil and Plant Research of Syiah Kuala University to present. Research interest including soil physics and chemistry. Personal webpage: https://fsd.unsyiah.ac.id/sufardi/

Mustaqimah's research focus on Agricultural Machinery for sustainable agriculture practices, Renewable energy for agriculture and Material Engineering. https://fsd.unsyiah.ac.id/mustaqimah/

Agus Arip Munawar's research interests: (1) Artificial intelligence in agriculture; (2) The application of a rapid and non-destructive method (i.e Near infrared reflectance spectroscopy (NIRS), Ultrasound, Electronic Nose) in predicting quality attributes; (3) Modelling and simulation. Webpage: https://fsd.unsyiah.ac.id/aamunawar/

CHAPTER 2

Sustainability in Home Garden Interventions to Improve Food Security: Results, Challenges, and Future Directions

Elisa Domínguez-Hernández, Claudia Hernández-Aguilar, Martha Elena Domínguez Hernández

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Food and nutrition security (FNS) is a priority for human development since different facets of malnutrition still prevail in many parts of the world. Home garden interventions (HGI) have been proposed to improve FNS, generally obtaining positive results. This review aimed to evaluate reports of HGI, discussing their characteristics and outcomes in terms of three sustainability dimensions (social, environmental, and economic). A total of 40 papers (n-number of papers) were included, mainly published since 2009. According to literature review, measurement, or discussion of economic (productivity, n=20) and social (diet improvement, n=33) outcomes has taken precedence over environmental ones (agrodiversity, n=15) in HGI's impact assessment (IA). Furthermore, sustainability has not been assessed beyond the continuity of the proposed changes (n=5). Future HGI should apply Systemic-Transdisciplinary approaches with adequate metrics and multidimensional IA methodologies linking FNS and sustainable development. This would allow a contextualisation of the research, establishing the current situation of the study system and identifying precise needs. Also, it would be possible to identify and monitor trade-offs and synergies of the intervention. Such approach would generate a strong body of scientific evidence and awareness of the benefits of a sustainable agricultural system in the prevention and treatment of the double burden of malnutrition (hidden hunger and overweight/obesity).

Keywords: Food security, nutrition, horticulture, systems thinking, transdisciplinary.

2.1 Introduction

Food and nutrition security (FNS) is a priority for global sustainable development. Substantial progress has been made over the last 50 years to reduce caloric deficiencies and food shortages through increases in agricultural production, particularly in terms of grain staples [1–4]. Thus, the percentage of hungry people decreased by almost 50% from 1990 to 2015 and the famines

that afflicted humanity for centuries have been practically eradicated in most parts of the World. However, undernutrition is still a problem growing in numbers since 2015 and over 820 million sufferers worldwide [5].

Ensuring adequate and balanced nutrition in the World's population remains a challenge. On the one hand, the poor intake and/or absorption of high-quality protein and micronutrients such as zinc, iron, vitamin A, and vitamin B12, also called "hidden hunger", is a constant problem for 2 billion people in developing countries (Figure 2.1) [6–8]. On the other hand, the World faces non-communicable diseases (NCD) related to excessive calorie consumption [9]. According to a report [5], overweight and obesity in adults are growing at an accelerated rate worldwide (almost 40 % in 2018). Likewise, overweight in children show signs of increase in the last decades (Figure 1) [10]. Adding to the complexity, unbalanced diets have caused a situation where hidden hunger and overweight/obesity often coexist in the same territories, in what is known as the "double burden" of malnutrition [11, 12].

In a broader sense, these challenges relate to the sustainability dimensions of food production systems [13]. Although agricultural intensification has improved the availability of food; important changes in the environmental dimension due to, for example, emission of greenhouse gases, loss of biodiversity, and pollution of water have been generated [14–16]. At the social and economic level, agricultural specialization ensued the globalization of nutrient sources to a few crops [17], which in turns may explain the slow progress to meet the protein and micronutrient needs of the population in various countries. In addition, environmental changes such as erosion or climatic variability have affected the livelihoods of individuals; particularly in rural areas, which in turns determines their ability to work and generate resources to access food and improve their nutritional status [2, 18–20]. Humanity faces the need to make food production more sustainable, and this implies promoting agricultural policies as well as agricultural R&D focused on improving the production of diverse and nutritionally dense foods [21, 22], which also guarantee resilient, adaptable, and productive agricultural systems, by implementing practices that conserve natural resources, are culturally acceptable and have reduced ecological impact [23–26]. Therefore, in the Sustainable Development Goals, the nations of the World seek to accomplish food security, hunger reduction, improved nutrition, and sustainable agriculture [27, 28], all of which are especially challenging in the ever-changing conditions created by politics, economics, climate change, globalization, natural resource depletion, population growth [29], and health crises such as the COVID-19 pandemic [27].

There is a need for approaches that consider the complexity of both the food production system and the described FNS situation [30–32]. In this context, horticulture could help addressing the issues described; as it is part of local food production systems in both developed and developing countries, in both urban and rural settings [33–37]. Indeed, horticultural interventions have been proposed to improve the FNS of vulnerable population groups [38–43]. In the case of home garden (HG) interventions, previous reviews have already attempted to evaluate their impact in nutritional and livelihood outcomes [19, 30, 44–47]. These systematic reviews have established valid research needs in terms of design quality, scientific rigor, and nutritional impact assessment. Nevertheless, the outcomes related to the sustainability of the food system have not been examined to the same extent. In this context, the aim of this paper to offer an overview of literature about HG interventions; to review and discuss their impact in terms of reported social, economic, and environmental indicators. As they provide insight into the research needs in sustainability assessment of such nutrition initiatives.

2.2 Methodology

Papers were obtained from searches in online databases (Scopus, Web of Science and PubMed), using a combination of keywords [(garden*) AND ("intervention" OR project OR program OR "horticultural intervention" OR "intervention trial") AND (nutrition OR "food security")]. Re-

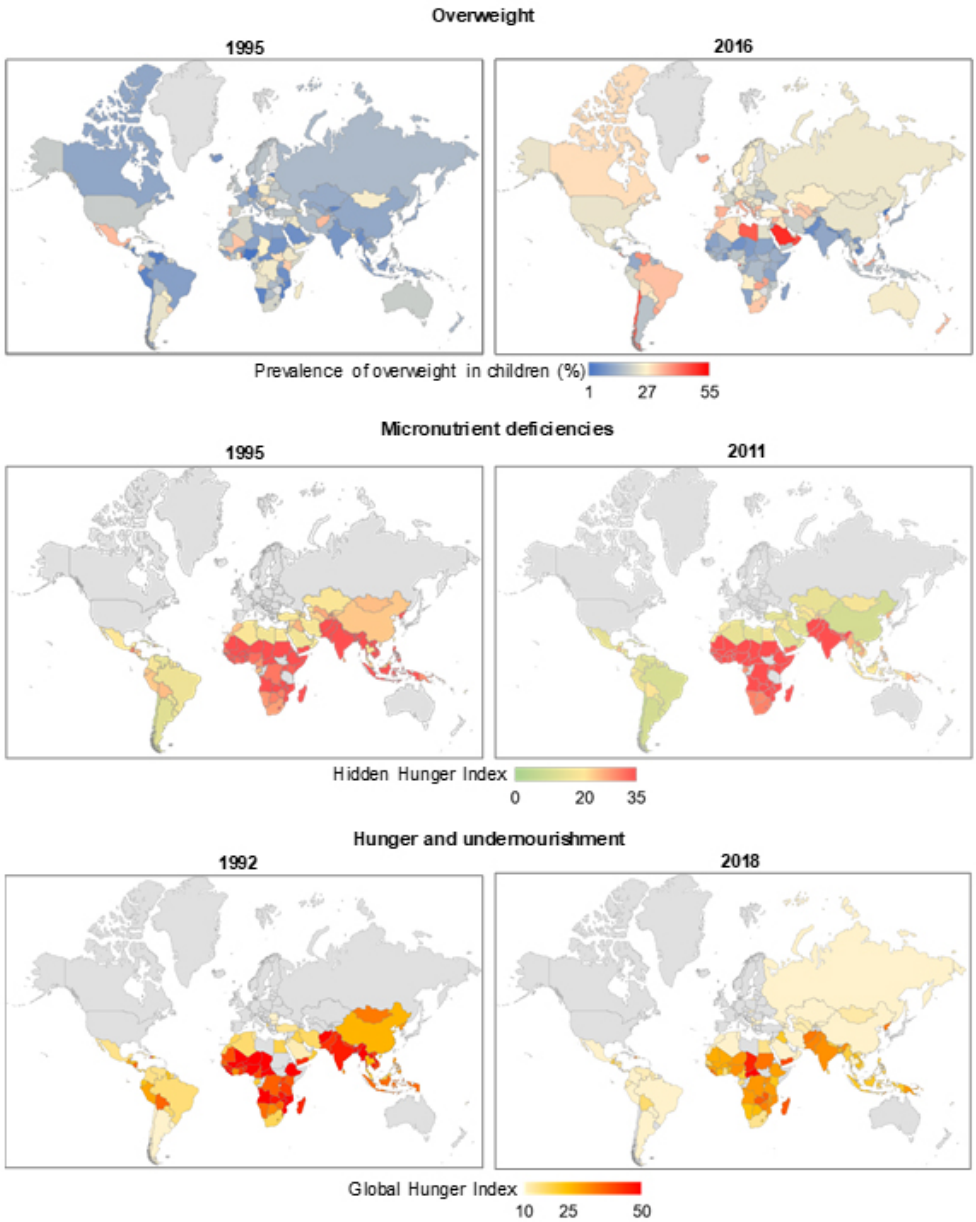

Figure 2.1: *Configuration considered for analysis: Challenges for food and nutrition security a) Overweight, b) Micronutrient deficiencies and c) Hunger and undernourishment. Based on data from [8, 48, 49].*

sulting articles were screened using, first, their titles and abstract (written in English), and then a read and re-read process. The projects included in the review consisted of interventions, experimental projects, or case studies. In these gardens were used, established, improved, or promoted; to produce a nutritional effect on a target group (also known as participants, actors, or beneficiaries).

The type of garden settings included were backyard/home/house/homestead, in both urban and rural locations. Preference was given to papers reporting results of interventions, which were published in peer reviewed academic journals over 20 years (1999-2019). Reports from non-government organizations, books, and book chapters, as well as reviews, comment, legal and conference papers were not considered. We do not attempt to evaluate the design quality and strengths/weaknesses of the studies, as this has been addressed in several reviews over the years. By using peer-reviewed research we expected that the evidence has already been evaluated and deemed suitable within the discipline of interest. Both in methodologies and results, and thus, was able to reach publication stage.

2.3 Results

A total of 40 academic papers were selected as relevant and therefore included in this review. Most of them were published between 2009 and 2019, and detailed research projects done in 16 countries, most of which consisted in low-income countries in Asia and Africa (Figure 2.2a and c). Twenty-seven journals published the selected reports on gardening interventions (Figure 2.2b), however, only four of them published three or more of the reviewed papers. The journals were categorized under a variety of subject areas: Medicine, health, nutrition, and nursing (48.2%), Agricultural and Biological sciences (22.2%), and social sciences (21%). This shows the diverse interests in these types of interventions and, to some extent, the disciplinary scope of the reports. The studies were published in the journal compatible with the objective of the research or the characteristics of the intervention.

Selected HG interventions generally consisted in the establishment, improvement, or diversification of small-scale family-managed production units, implemented along with educational components in nutrition, agriculture, hygiene, and health (Table 1, see Appendix). In a few cases, HG were promoted via training in farmer groups or organizations, at home via mentors or at school, occasionally using participants as agents of change (Table 1). Intervention participants usually received practical agricultural/horticultural training to plan, plant, and maintain the gardens (Table 1). This training was necessary for new gardeners, but also for experienced ones since several interventions introduced new garden models, crops, add-on livestock components and improved or organic practices [50–52].

This review examined, the characteristics and results of the selected papers according to the dimension (social, economic, or environmental) to which they belong, to understand how sustainable gardening interventions are. The classification carried out is by no means definitive since there is always overlap between the different dimensions and their outcomes. This will be detailed and discussed in the following sections.

2.3.1 Social Dimension

In a large part of the studies, social elements were the main outcomes measured to assess the impact of HG interventions. According to the requirements of this review, all interventions sought to improve FNS aspects in the beneficiaries. However, the aims seemed to be related to the nutrition challenges the different countries face (Figure 2.1). Papers from Africa or Asia mostly referred to food insecurity and undernutrition alleviation. Meanwhile, in higher income countries, it was more common to find gardening interventions to aid in the fight against overnutrition and its burden of disease. Although some addressed food insecurity issues in underprivileged

populations. Other directly measured social outcomes were related to household (HH) wellbeing, both in developed and developing countries. This speaks to the diversity of problems that have been addressed using horticulture-based interventions.

Food and Nutrition Security

In terms of effectivity, 70% of reviewed HG papers reported positive FNS results for participants in terms of increased availability, access and/or consumption of nutrient rich food, often related with increased diet diversity (Table 1, see Appendix). Spill-over benefits were also noted in non-participants, as surplus garden produced foods could be shared or made available in local markets [53–55], but also because gardening could be adopted by neighbours themselves due to the participatory nature of many programmes [32, 56].

Studies that measured nutritional and health status; however, were often unable to prove impacts in nutritional or health status measures, such as anthropometry, morbidity, and biochemical markers due to previously noted limitations in their design (e.g., sample selection, lack of power, study length or deficient randomization) [19, 44, 49]. Despite these shortcomings, previous reviews on HG still regard HG interventions as valid options to address food insecurity, micronutrient deficiencies, and undernutrition via intermediate pathways (Figure 3). It is recommended integrating other strategies, such as supplementation and continuous food and nutrition education and sensitization campaigns at a community level to improve nutritional status outcomes [50, 51, 57].

At the other extreme of malnutrition, only five reports related to interventions for the prevention of obesity and NCD in vulnerable populations by promoting healthy eating [mainly increase fruit and vegetable (FV) intake]. They mainly consisted in short-term evaluations (feasibility and pilot studies) with limited numbers of participants, so the evidence cannot be generalized, however, some increases in FV consumption measures were recorded in populations like cancer survivors [58–60] and seniors [61]; other positive outcomes were trends towards improvements in weight status and blood pressure, or blood lipids (in South African studies [62]). These results concur with other studies, relating to community and school gardening: the which have showed promise in addressing overnutrition problems and reducing consumption of unhealthy food [63–66].

Further efforts should be devoted to assessing the suitability of HG interventions to target nutrition related NCD and the double burden of malnutrition in middle- and low-income countries. Even if the evidence for improvement in nutritional status is not strong, in the long-term; diversified gardens have shown to be an important part of a food and nutrition system that addresses some of the underlying causes of different FNS issues (both from under and overnutrition), such as ignorance, inadequate feeding practices, reliance on staple/energy-dense cheap foods and limited access to nutrient rich food, for example [21, 39]. These causes correspond to the pathways in Figure 3, and future studies should focus on measuring them as outcomes of these interventions since they are more attainable and easier to monitor than following nutritional status changes. Also, additional evidence is needed to support the possible benefits of home gardens for the prevention of nutrition related NCD.

Nutrition Education and Knowledge Preservation

The attainment of knowledge and skills in nutrition, health and agriculture were a common goal of gardening interventions. Hands-on horticultural practice is often implemented along with nutritional education, both present synergistic effect in the FNS benefits of the participants, constituting an important pathway shown in Figure 2.3c [44]. HG studies have reported improvements of health awareness and nutrition knowledge scores in maternal and young participants after an intervention. These results were associated with improvement in dietary diversity, dietary and feeding practices, and child health outcomes in developing countries [67–71].

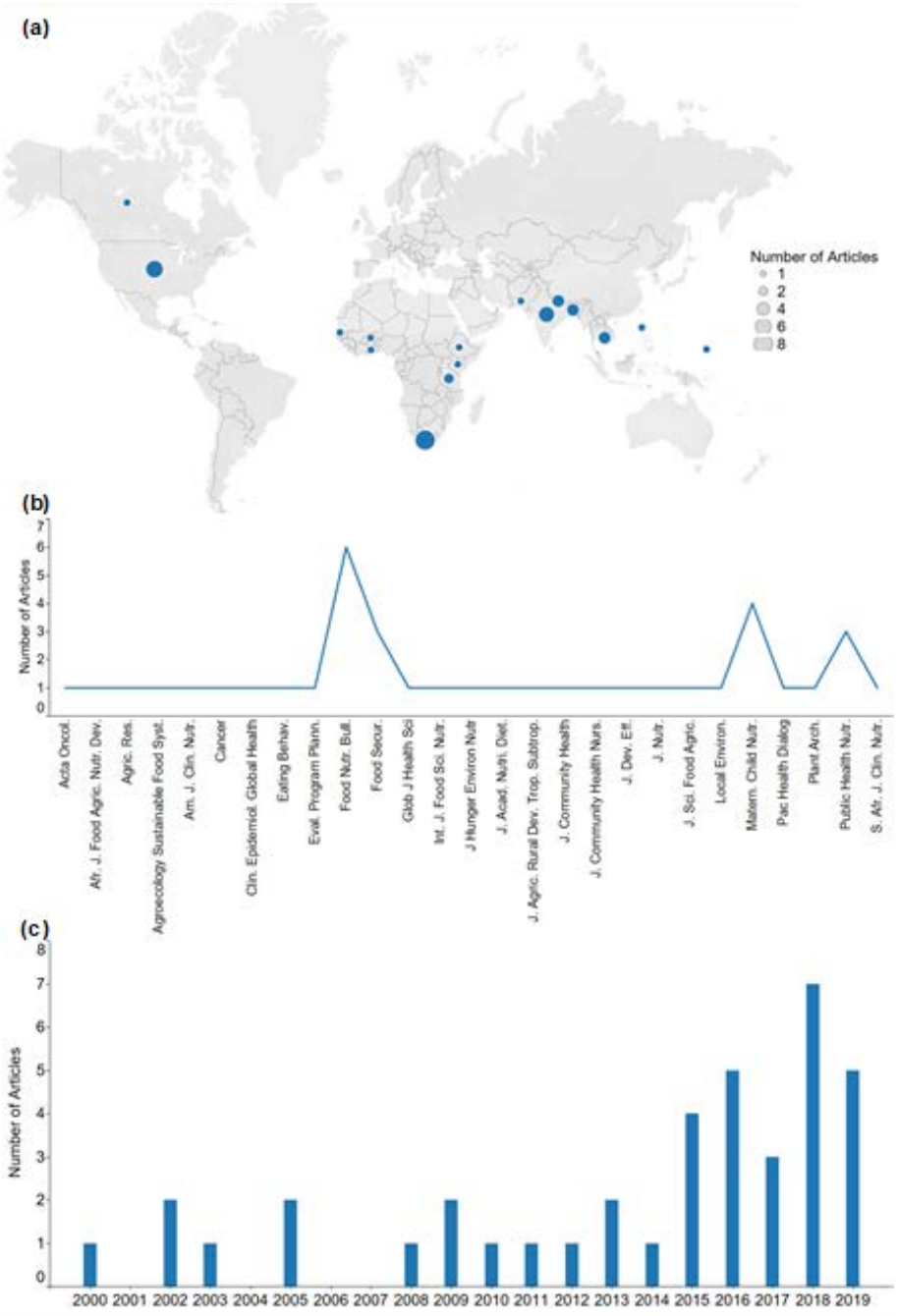

Figure 2.2: *Overview of the selected home gardening intervention studies. Number of studies per (a) intervention country, (b) journal and (c) year.*

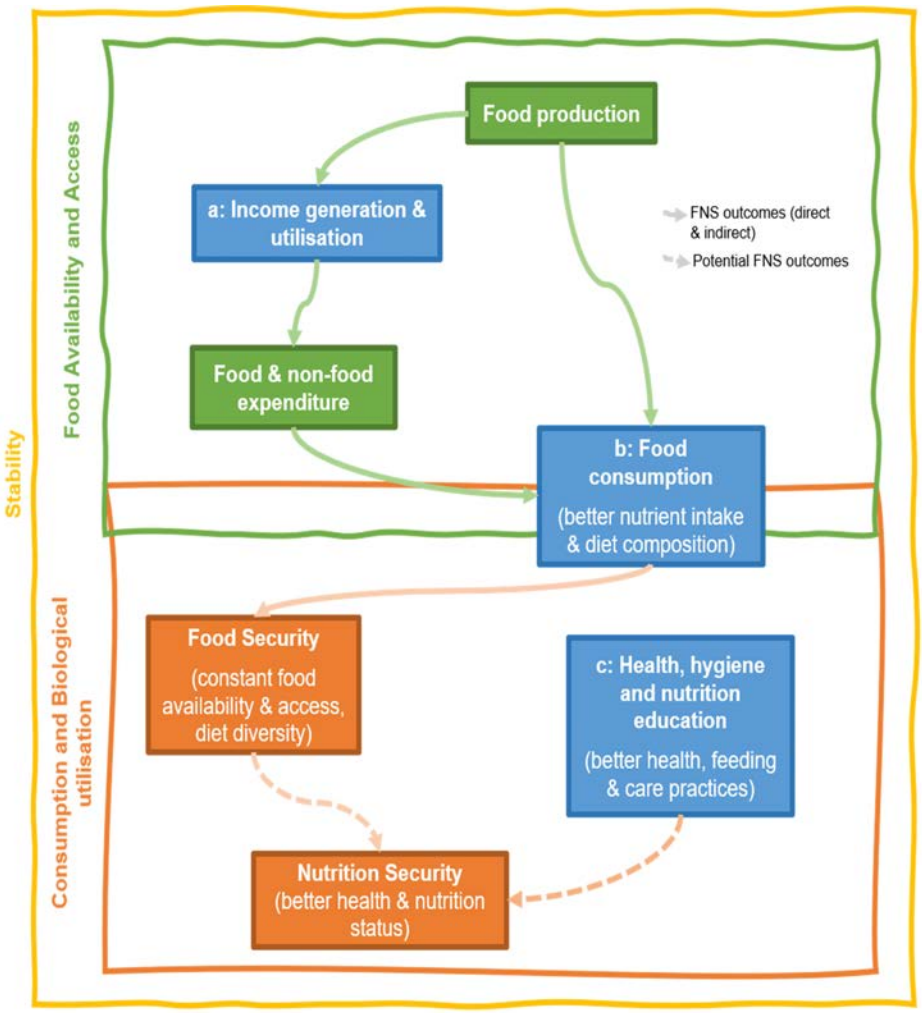

Figure 2.3: *Linkages between horticultural production and nutrition. Main pathways (a, b, c) to improve nutrition during home garden interventions, and the dimensions of Food and Nutrition Security to which they belong.*

Reviewed literature indicates that education and sensitization can help addressing cultural or personal barriers and prejudices against healthy foods, adoption of adequate dietary practices and equitable intra-household food allocation [72, 73]. For example, interventions improved infant feeding practices by teaching the importance of exclusive breastfeeding [72, 73]; other times, education was aimed to correct food taboos and beliefs which limit access to food in the pregnancy [51].

Previous interventions with school children and youth have shown that garden exposure promoted acceptance of healthy eating behaviours and attitudes towards fruits and/or vegetables, which may lead to changes in their diet [74–76]. In the present review, a couple of studies from North America also reported more positive attitudes and beliefs towards garden produced healthy foods, and activities like cooking or eating them [61]. Similarly, participants tended to recognize

the importance of FV as part of a healthy diet and were motivated to adopt one [58–60].

It has been observed that changes in behaviours and/or attitudes were frequently related to nutrition lessons/workshops during the school or community garden interventions [75, 77–80]. Furthermore, gardens can be used to preserve, reconnect with, and transfer traditional practices, spiritual views, food values, and other aspects of the knowledge base of aboriginal [81, 82] and migrant communities [55, 83–86]. This could be an interesting topic for future research during the home garden interventions. it is relating to the development of culturally acceptable practices, community integration and ownership, which could contribute to increasing the success of the programs.

The overall effectiveness of gardening interventions might reflect their ability to engage target populations as active participants in an experiential learning process [87]. Authors often recommended strengthening (or adding) continuous education and training components to the intervention and promoting knowledge communication and sharing to address limitations, broaden the impact and enhance the benefits of them [50–52, 88–90].

Psychosocial Aspects, Equity, Community Participation

Horticulture offers a series of intangible benefits for those who take part in the activity and spend time in food producing landscapes. Most evidence of this has been obtained from community gardening studies and very vulnerable populations [42, 60, 84, 85, 91–93]. However, at least 50% of the presently included papers reported non-physical wellbeing and quality of life accounts from the participants, mostly showing positive results.

It was seen that HG beneficiaries not only enjoyed gardening; but also formed emotional and spiritual connections with the process of growing their own food, which in turn can influence their food values and dietary choices [61, 94]. Also, gardening interventions often encourage or strengthen community and family integration and a sense of belonging or unity in the participants [86, 95]. Interactions occur as people work together, share the harvest, or spend time with others in and around gardens, or participate in group activities like nutrition workshops and cooking lessons. Social integration/cohesion improvements were associated with better cognition measures in senior gardeners [94] and well-being in people adapting to a new country [83, 86]. Sharing the harvest has been also a way to improve social standing of participating HH, whose neighbours see as “giving” and “well-to-do” [96].

Gardening activities can be challenging, but by taking part in them, and learning about different intervention topics, participants took pride and became more confident in their own skills [89, 94]. Interventions were often targeted to women, so the aspects of education and capacity building have been related to empowerment. Women’s empowerment has been measured using composite indexes and mixed methods to quantify their changes in HH influence. Reported results showed women participants gained control over HH food production and means of income generation, thus lifting their status in society, self-esteem, and their decision-making ability, even in male headed homes [53, 89, 97]. Women’s participation in gardening often comes with a higher workload, which has been previously associated with negative impact in care provision [19, 98], however, measures of time spent in the garden indicated no conflict between the two activities [50, 99]. Further studies should examine this possible trade-off of women’s empowerment to avoid worsening child and HH nutrition outcomes.

The results presented in this section show that FNS centred HG interventions can be enriched. It could be by evaluating their effect on emotional, affective, and social integration outcomes as they could be important for maintaining the changes [91]. Indeed, study participants have stated that engaging in hands-on horticultural practice was a satisfying part of the intervention and a motivation for continuous participation [58, 59, 100, 101].

2.3.2 Economic Dimension

In developing countries, financial impact has been widely mentioned, as part of the objectives of the interventions is to promote income generation or cost savings (Table 1), generally reporting positive results. However, it's worth saying that these specific benefits were not directly reported in most documents, rather discussed, or used to explain changes in FNS outcomes (impact pathways), which suggests a gap between, what is mentioned, and is demonstrated in the studies.

Productivity, Income, and Savings

The improvements made to agricultural practices during the interventions often led to increases in horticultural productivity among the beneficiaries, which were used as a proxy of intervention success. For example, studies in Bangladesh, India and Cambodia reported increases in the number of plots dedicated to horticulture [50, 52, 102]. Other studies in Africa reported increases in production and yield of the promoted FV [103, 104]; these increases in plant productivity can translate into higher nutrient availability for the HH [50, 105]. The literature also indicates greater economic returns in HH that have diversified and mixed gardens [52, 67, 73, 106]. In some instances, a productive perennial diversified gardening eventually allowed beneficiaries to acquire chickens and ducks at the time of evaluation, thus increasing HH assets [39, 52, 73].

The sale of surplus horticultural production can improve the financial status and welfare of beneficiaries by generating supplementary income when it is sold in local markets [39, 52, 53, 107]. Another widely mentioned benefit of HG interventions is a lower expenditure in garden produced foods of animal and plant origin [54, 107, 108]. In fact, a study from the USA reported that the cost saving benefits of gardening exceeded 300 USD during the summer season (high productivity, 5.9 m2) thanks to the high market value of organic produce [55]. These monetary benefits can translate into greater purchasing power. It has been observed that the income generated is generally invested in, for example, food items that are not produced in the garden, education (paying school fees and/or materials), as well as covering gardening production costs [39, 52, 53, 69, 99, 100]. This seems to indicate that the extra income is allocated to cover basic needs that improve HH wellbeing in the long run, contributing to poverty alleviation. Also, economic, or financial benefits are often cited as the reason for continued participation in the activities promoted during the intervention [53, 96, 100].

Economic efficiency

Cost-effectiveness of the intervention was mentioned in five reviewed papers of recent publication (2014-2018), but only quantified in 2 instances. Including these economic efficiency measures help validating food-based approaches as solutions for problems that could be solved with alternative health interventions, but it is uncommon in reports from developing countries. This parameter was related to maximizing the economic and nutrition benefits of an intervention for a given investment, reduction of costs and eventual expansion or continuity of the programmes [109]. The results from the 2 papers indicated that gardening interventions can be as effective as supplementation or medication to prevent micronutrient deficiencies or morbidities. However, in the long-term as they also generate positive effects in areas of HH wellbeing that may not be of economic nature; it has been advised to not use as the sole criterion for effectivity [50, 62].

2.3.3 Environmental dimension

In the case of gardening interventions, the evaluation of economic and social aspects has taken precedence. Few indicators or outcome measures relating to natural resource management (NRM) or ecological aspects of production have been used to evaluate the impact of gardening interventions. A review on community gardens also emphasized the lack of evidence pertaining

to environmental benefits, environmental equity, and environmental sustainability as a need for future research in the topic [110].

Agrodiversity and Ecosystem Services

Although there is not much information in the studies reviewed; the most relevant principle is the promotion of agrodiversity in the gardens, whose main objective was increasing productivity, and reduce seasonality. Indeed, dietary improvements, vegetable consumption and utilization have been positively associated with garden diversity [50, 54, 56, 111]. Twenty-five papers mentioned the number of crops planted or the integration with livestock production or conservation of diversity, stating increases or conservation.

In addition to productivity, diverse gardens and perennial production could generate other ecological benefits. Establishing intercropping and polycultures can help control pests, reduce weed competition and climate shocks, thus lowering the risk of crop loss [112–114], which could explain a reduction in the incidence of said problems after training and adoption of sustainable practices in Bangladesh [50]. A vegetation covers can reduce water loss, soil erosion, and maintain fertility (mentioned in [68]). Finally, by increasing the number of flowering plants, pollination, pollinator diversity and plant genetic material dispersion are promoted [115, 116], in this context, the conservation of traditional and culturally important plants could be an important benefit (as mentioned in [55, 83]). Together, these ecosystem functions and services make it possible to increase the stability of the garden agroecosystem and HH's livelihood and FNS [117–119] and have been mentioned as potential benefits of HG [120]. According to our review, no recent paper has directly examined these kinds of services in the context of the outcomes of a FNS intervention. This lack of information is unfortunate, and it shows the relationship between food production and the NRM base has been overlooked in practice.

Agricultural practices

Even if ecological impact has not been explicitly evaluated, successes and challenges mentioned in previous sections have been associated with degrees of adoption of environmentally sound and low input practices. For example, studies in South Africa stated that gardening HH reported problems related to improper fencing, water use and availability, and insufficient access to pest/disease chemical control agents [54, 103], which kept appearing in subsequent evaluations [96]. These problems occurred in a large percentage of beneficiaries (41-72%) even when the intervention included training in water conservation and integrated pest management.

Other problems related to agricultural practices have been associated with inadequate design, e.g., introducing plants or garden models that are not adapted to local conditions, are difficult to maintain or include time-consuming practices; this could cause disadoption [88] or even adaptation if the participants are sufficiently motivated to continue gardening and overcome the limitations [100]. Unfortunately, the promotion of gardening and continuity based only on productivity motivations (economic or to maintain social standing) can also signify the continued use of agricultural methods that may not be environmentally friendly, e.g., using chemical pesticides and fertilizers [50, 103, 121]. Even if the benefits are preserved for decades, inadequate NRM practices have been shown cause environmental degradation (loss of soil fertility, loss of biodiversity) as well as negative health effects (reduction in water quality, agrochemical exposure), which will eventually compromise the livelihoods and nutrition outcomes of the beneficiaries [122–124].

In contrast, projects undertaken in developed countries often highlighted; that an important motivation for beneficiaries to adopt home gardens was precisely to learn how to produce FV in a clean and organic way, and to increase their access to healthy foods [55, 83, 94]. To create a similar view in developing countries, it is necessary to build an environmental conscience and strengthen the links between safe agriculture and FNS, and the long-term consequences

of unsound practices, using transdisciplinary approaches. This could be done by, for example, consulting with the target population and integrating the local/traditional views of agriculture, food, nature and health to the design and evaluation of the intervention [41, 81]. Also, it is necessary to offer continuous support or extension services to overcome limitations and prevent returning to conventional practices by providing advice on low-cost agroecological/organic solutions. An encouraging example of this approach was found in a Pakistani project. It was largely focused on promoting organic practices and disaster recovery gardens, and devoted large efforts to create awareness in the dangers of pesticides [89]. This led to an overwhelming adoption of biopesticide use and integrated pest/weed management, as well as perceived improvements in some nutrition and economic outcomes, as well as psychosocial measures.

In summary, it is possible to observe in Table 1 (see Appendix), a list of selected home gardening interventions where their characteristics and results found by the various authors are observed.

2.4 Discussion

2.4.1 Sustainability of the Interventions

"Sustainability" has been addressed or discussed in gardening interventions, but it has been understood as the "continuity" or "longevity" of the promoted changes and obtained benefits after completion of the projects [53, 96, 100, 104, 125]. This definition of sustainability, although incomplete has been useful, since this type of articles have identified some of the determinants for disadoption, continuance or adaptation of practices. Thus, providing useful recommendations for the design of future interventions. In this way, the design of HG interventions now includes more comprehensive approaches to address malnutrition, including both human and environmentally friendly approaches in their design and implementation. Previous reviews have highlighted as a pre-requisite of a HG intervention success and a sign of their "holistic nature" (mentioned as natural capital investments [19, 44]. In some cases, interventions use participatory research approaches to solve nutrition issues. Thus, creating partnerships with the target population so that their priorities and needs are considered for the intervention design [126–129]. This type of research allows for dissemination of the interventions, even if beneficiary groups are small [56], and is generally considered to produce lasting benefits due to community engagement [41, 83, 89, 130]. However, as seen in the previous sections, the evidence base of these interventions is fairly limited to social and economic indicators.

As mentioned earlier, sustainable systems should be based in three pillars: profit, people, and planet, which means supporting economic and socially just development in an environmentally compatible way [131]. Increasing yields and productivity of gardens is the first step towards improving FNS. Adopting environmentally sustainable approaches during an intervention is a necessity in terms of achieving stability in the dimensions of food availability, access, and utilization [132]. Thus, HG interventions should not be considered sustainable just because the end-line state is preserved over time and without understanding the impact in the natural resource base that may be occurring upon adoption of certain practices.

The lack of evidence regarding the environmental outcomes of an intervention is, therefore, unfortunate and it also indicates how environmental and NRM aspects are mainly seen as "inputs" and not so much as outcomes of a FNS intervention (se models presented in [131] and [132]). More efforts should be devoted to rectifying this situation, however, a survey of current agriculture-nutrition interventions showed that impact assessment priorities remain skewed towards socioeconomic factors, as only 7% of the projects contained one indicator (water quality) related to the how an intervention can influence NRM and the environment [135].

2.4.2 Future directions

Systemic-transdisciplinary approaches have the potential to increase the sustainability of HG interventions. By using indicators or outcome measures from all three dimensions it would be possible to identify trade-offs and synergies between the different dimensions before, during and after the intervention is established [136, 137]. It would allow a holistic view of the complex interactions that exist between FNS and the food production system. Thus, furthering our understanding of the pathways by which interventions influence nutrition in the beneficiaries [138].

Systemic approaches have been used for ex ante and ex post impact assessment in agriculture-nutrition projects showing promising results linking sustainability (or sustainable development) and FNS [41, 139, 140]. These studies used participatory processes to evaluate and compare intervention outcomes. Systemic approaches become Transdisciplinary by integrating stakeholder knowledge (a.k.a. non-disciplinary knowledge) to an expert/academic/disciplinary FNS improvement strategy. Although there are other characteristic features that should be considered, such as the self-investigation of the stakeholders or some of them, in such a way that the union for a solution to the problem is achieved, mutual learning, etc [144, 145]. Of this manner, knowledge of academics and stakeholders is shared between each other at all research stages, generating innovative solutions for real-world problems [141–145]. This would also intensify participant involvement during a horticultural intervention from information and consulting to empowerment and ownership [146].

A Systemic-Transdisciplinary approach also requires interdisciplinary academic collaboration. With rigorous research and expertise sharing across disciplines, the quality of the studies could be increased [144], and all aspects of sustainability considered. In the context of an intervention, cooperation between agricultural and nutrition scientists would allow the generation of adequate outcome/indicator metrics to explore its proximal benefits. Also, these scientists could encourage the realization of field experiments to validate the agricultural/horticultural practices promoted and adapt them to different geographical contexts [89, 147, 148]. Social, political, and economic scientists should also be consulted by agricultural/biological experts to account for factors such as markets, laws and regulations that influence sustainability, FNS and household decision-making processes.

We acknowledge that changing from a reductionist (single outcome) research methodology towards a Systemic-Transdisciplinary one is not simple, and it is one of the great challenges of truly holistic approaches. Measuring outcomes from all three dimension in FNS interventions leveraging agriculture is work intensive; as it requires a higher number of variables to be quantified and recorded, as has been found by our own research group in Mexico [143, 149]. Additionally, for HG interventions, multidimensional sustainability evaluations would require the development or adaptation of indicators and sustainability assessment frameworks [148, 150]. Regarding indicator selection, it has been recommended that interventions focus on results they may affect in a more direct way than nutrition status [135], such as diet diversity or variety, food consumption, income, and food supply and access. Inclusion of measures for energy or water use efficiency, soil fertility, weed/pest incidence and even some ecosystem services was also needed to address stakeholder concerns and specific challenges of local food production. In the long-term their monitoring would help maintaining resources and biodiversity, as well as building HH resilience [41, 119].

Finally, rigorous inter and transdisciplinary research across regions would be necessary [145]. This would mean the time required for developing, implementing, and assessing the multidimensional impacts of an intervention may be higher. Perhaps more importantly, it would be crucial to eliminate institutional and disciplinary barriers, as well as personal prejudices and group research preferences to ensure cooperation between scientists and actors [151]. However, we believe all this is justified in terms of gaining a better understanding of the elements and processes that contribute to improving FNS and sustainability at a local and even global level. Cooperation

would also allow for expertise sharing across regions [145]. Thus, expanding the research landscape towards low- and middle-income countries and addressing both over and undernutrition issues.

2.5 Conclusions

The literature review supports the validity of HG interventions to improve food security by integrating agricultural aspects and nutritional considerations. Home gardening interventions mainly improve the diet of the households benefited directly and indirectly by them. However, the evidence base has tended to consider mainly undernutrition and micronutrient deficiencies; with few studies treating nutrition related NCD and the double burden of malnutrition, a rising issue in recent times.

Very few studies have used holistic research approaches that simultaneously considered the effects in the social, economic, and environmental dimensions of the intervention. Additionally, even if the interventions stated or discussed positive or negative effects in all three dimensions; they were often not demonstrated within the study, or their report was not considered relevant.

Further efforts should be devoted to developing adequate metrics and assessing the environmental outcomes of HG interventions, as well as multidimensional methodologies that offer a complete view of the sustainability of an intervention. This also implies using Systemic and Transdisciplinary research processes that address the complexity of the systems involved (FNS and productive) and foster cooperation between researchers and stakeholders in all stages of the intervention.

Transdisciplinary methodologies could be a support to carry out with rigor and in a broader sense the home garden interventions to improve food security, presenting their application in their various characteristic features as one of the challenges in current research in some countries, mainly developing countries.

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About the Authors

Elisa Domínguez-Hernández is a Postdoctoral Researcher at the Autonomous University of Queretaro and is a member of the National System of Researchers. Holds a PhD in Systems Engineering from the National Polytechnic Institute - ESIME Zacatenco and a double M.Sc. in Animal Science and Food Science from the Swedish University of Agricultural Sciences and the University of Helsinki. Her research relates to Sustainable Food and Nutrition Security, understanding, and studying, the different elements of the food production system (farm to table), and their impacts on the supporting human and natural resource systems.

Claudia Hernandez-Aguilar is a professor and researcher of the National Polytechnic Institute, within the Graduate Program in Systems Engineering of ESIME Zacatenco. She is the leader of the Research Group on Sustainable Biophysical Systems for Agriculture, Food and Medicine. She is a member of the Mexican Academy of Sciences and the National System of Researchers (Mexico). Since 2012, she has been a member of the Editorial Committee for the International Agrophysics journal. She has published her research in international journals and has received over 500 citations. Her focus is the use of engineering e.g., sustainable biophysical methods and photothermal techniques to improve society's quality of life and wellbeing. In times of pandemic, she has proposed educational interventions for the consumption of nutraceutical and low glycemic index foods, as well as the care of the other, the other and the others. She has trained young transdisciplinary researchers for the past 15 years, emphasizing the need for awareness, conscience, rigor, and humanism in the research process and of a Transdisciplinary systemic view on the impact obtained from it. Motto: Transform yourself, to transform your world.

Martha E. Domínguez-Hernández is a professor and researcher in the Department of Agronomic Sciences of the National Autonomous University of Mexico, as well as a member of the National System of Researchers. She is interested in the agricultural application of multidimensional sustainability impact assessment, participatory research, systems thinking and geographic information systems. Using these tools, her research focuses on the understanding of Mexican

Agroecosystems and sustainable intensification of production to meet the food needs of a growing population while reducing environmental impact.

APPENDIX

Table 1. Characteristics and outcomes of selected home gardening (HG) interventions.

Country	Participants/ beneficiaries	Characteristics	Economic	Social	Environmental	Pilot study	Type of measurements	Reference
Bangladesh	HH, women (active vs former participants)	Examines continuity of all-year HG & NE programme designed to improve vitamin A status, evaluation of FNS, continuity, as well as economic & social benefits.	↑Productivity ↑Income ↑Purchasing power	↑Women Empowerment ↑Consumption (FV) ↑Agricultural knowledge	↑Agrodiversity		Quantitative	[53]
	Women	HG programme, including training in organic gardening, cooking & NE to ↑ availability & consumption of NR vegetables.	↑Productivity (all-year, harvest/yield, garden size) ↑Commercialisation	↑Variety (vegetable) ↑Nutrient yields ↑Female workload ↑Food utilisation (↓waste) ↑Agricultural knowledge ↑Women Empowerment	↑Agrodiversity (new crops) ↑Management practices (Planting, irrigation, seed, org. fertiliser etc.)		Quantitative	[97, 99]
	Women		↑Productivity (all-year, harvest/yield, garden size) ✓Cost-effective intervention	↑Consumption ↑Nutrient yields ↑Female workload ↑Food utilisation ↑Social integration (sharing) ↑Women Empowerment ↑Agricultural knowledge	↑Agrodiversity (new crops) ↑Management practices (×seed, water availability)		Quantitative	[50]
Burkina Faso	Women	All-year HG & NE programme w/ community monitoring (older women, health promotors) designed to improve production & consumption of NR foods (FV, animal-source), as well as child health outcomes.	↑Productivity	↑DD ↑Nutrition knowledge/Care practices ↓Child morbidity ↑Women empowerment ↑Community participation	↑Agrodiversity (promoted crops)		Quantitative	[67]

Table 1. Characteristics and outcomes of selected home gardening (HG) interventions (*Continued*).

Country	Participants/ beneficiaries	Characteristics	Economic	Social	Environmental	Pilot study	Type of measurements	Reference
Cambodia	Women and children (<18 months)	All-year enhanced homestead food production (diversified gardening & w/ or w/o fishpond) paired w/ NE/hygiene/BCC/gender training programme designed to improve micronutrient & weight status.	N.D.	↑/=Nutritional status (children's anaemia, women's vit. A)/weight	↑Agrodiversity (crops, fish)		Quantitative	[151]
	HH w/Children	All-year HG & NE programme w/ community monitoring (older women, health promotors) designed to improve production & consumption of NR foods (FV, animal-source), as well as child health outcomes.	↑Productivity (all-year) ↑Income (moderate)	↑Consumption (Nutrient rich plant foods) ↑Nutrition knowledge/Care practices =Child morbidity/Nutritional status ×Nutrition knowledge/Care practices	↑Agrodiversity (improved &diversified gardens)		Quantitative	[52]
	Women and children	Enhanced homestead food production (diversified gardening w/ or w/o fishpond) paired w/ NE/hygiene/BCC/gender training designed to improve diets, micronutrient status.	×Productivity (low season)	↑Women nutrient intakes/*adequacy =Children's nutrient intakes/*adequacy ×Dietary habits (snack foods)	↑Agrodiversity (crops, fish)		Quantitative	[152]
Canada	Seniors	HG partnerships for health as alternative to community gardens.	↑Savings ↑Land access	↑Psychosocial measures ↑Dietary attitudes/Food values ↑PA ↑Social interaction	N.D.	Yes	Qualitative	[94]
Ethiopia	Adolescents	School based NE + home gardening &community participation programme to ↑ attitudes, knowledge & DD. Explores predictors of DD.	↑Productivity (#gardens)	↑DD ↑Nutritional knowledge ×Nutrition & food prejudices	↑/= Soil fertility	Yes	Quantitative	[68]

Table 1. Characteristics and outcomes of selected home gardening (HG) interventions (*Continued*).

Country	Participants/ beneficiaries	Characteristics	Economic	Social	Environmental	Pilot study	Type of measurements	Reference
Ghana	Children	Mixed gardening (container) & livestock (poultry, egg, honeybees) intervention including input supply, organic agricultural training, NE (group & community) to improve health, consumption of NR foods, income generation (egg sales	↑Productivity ↑Income	↑Consumption (likelihood, eggs) ↑DD (Likelihood) ↑Nutritional status (child growth) ↑Care practices ↑Nutrition knowledge/Women empowerment/Community participation	↑Agrodiversity (Intercropping, livestock) ↑Management practices		Quantitative	[69]
India	HH w/children (<6years)	A perennial kitchen garden model (training, plant distribution according to season & demand) & NE to ↑ DD.	↑Productivity (#, size of gardens)	↑DD =Consumption (FV, Leg., Cer.) ↑Participation interest ×Food utilisation knowledge ×Agricultural knowledge	↑Agrodiversity (# crops) ↑Practices for RUE		Quantitative/ Qualitative	[102]
	Rural HH	Community based project- Provision of micro-credits, inputs & capacity building to improve FNS & income via diversification of HH activities (nutrition gardening w/ cash & food crops, mushroom production, livestock integration, food processing/cooking & recycling of crop waste).	↑Productivity/Diversification of activities ↑Income (↓poverty)	↑Consumption (FV, animal foods) ↑DD ↑Nutrition awareness ↑Food utilisation	↑Agrodiversity (Intercropping, livestock) ↑Organic fertiliser use		Quantitative	[106]
	Adolescent girls (10-19 years)	Community based interventions w/ kitchen gardening, supplementation & health promotion to improve availability of NR vegetables, ↓ anaemia & morbidity.	N.D.	↓Morbidity ↑Health, sanitation & nutrition knowledge ↑Nutritional status (anaemia)	N.D.		Quantitative	[70]

Table 1. Characteristics and outcomes of selected home gardening (HG) interventions (*Continued*).

Country	Participants/ beneficiaries	Characteristics	Economic	Social	Environmental	Pilot study	Type of measurements	Reference
India	Women and children (<60 months)	Mixed gardening & livestock (foraging laying hens) intervention including input supply, farm technology adoption training, BCC, HNE, to improve health, consumption of NR FV & eggs.	↑Productivity (# gardens, eggs produced) ↑Income (sales)	↑Consumption (eggs) ↑DD (Likelihood) ↑Nutritional status (child growth) ↑Hygiene/Care practices/Nutrition knowledge	↑Agrodiversity (crops, poultry) ×Management practices		Quantitative	[51]
	Rural HH	Kitchen gardening intervention to improve FNS, including organic production training & scientific advice, NE (utilisation & consumption of NR vegetables).	↑Productivity (all-year, yield) ↑Savings	↑Consumption ↑Women empowerment	↑Agrodiversity (types of veg.)		Quantitative	[108]
Kenya	HH w/children, neighbours (indirect beneficiaries)	Community-based participatory approach to address micronutrient deficiencies via horticulture & NE.	↑Productivity ↑Income	Children (direct/indirect: ↑Consumption ↑DD/Nutrient adequacy) Women: =Consumption/DD/Nutrient adequacy ↑Nutrition knowledge ↑Community participation	N.D.		Quantitative	[56]
Micronesia	Urban HH	Container gardening & improved cooking workshops & NE to improve health & nutrition through access to traditional foods (FV, staples).	N.D.	↑Consumption (↑promoted local foods, ↓processed foods) ↑Psychosocial ×Nutrition/Agricultural knowledge	×Management practices		Quantitative/ Qualitative	[88]

Table 1. Characteristics and outcomes of selected home gardening (HG) interventions (*Continued*).

Country	Participants/ beneficiaries	Characteristics	Economic	Social	Environmental	Pilot study	Type of measurements	Reference
Nepal	Mothers and children (<2 years)	Enhanced homestead food production programme (gardening+poultry), training, NE, BCC, cooking classes, health promotion, input distribution & community monitoring to improve nutrition status of participants.	↑Productivity (food availability)	↑Women's DD (low season, remote zone) ↑/=Children's DD ↑Extension/support ↑Community participation ↑Nutrition/Health knowledge	↑/=Agrodiversity (poultry)		Quantitative	[153]
	Rural HH	↑ income via production of high-value horticultural crops w/ extension & improve nutrition via education.	↑Productivity	↑Consumption (FV) ↑Nutrition knowledge (unacceptable levels) ↑Hygiene/nutrition practices/Food utilisation	↑Agrodiversity (# crops planted & eaten)		Quantitative	[72]
	Women and children (12-48 months)	Enhanced homestead food production programme (gardening+poultry), training, NE, BCC, cooking classes, health promotion, input distribution & community monitoring to improve nutrition status of participants.	↑Productivity (# Enhanced gardens)	↑Food Security ↑Children DD ↑*Nutrition knowledge/Care practices ↑*Child &women nutritional status	↑Agrodiversity (types of FV)		Quantitative	[73]
Pakistan	Women	Participatory programme to provide training & capacity building in nutrition, rehabilitation of agricultural practices (sustainable horticulture, ↓ in pesticide use/risk, livestock raising) in the aftermath of a devastating earthquake. No comparison.	✓ Commercialisation/livelihood rebuilding/Diversification of activities	✓Consumption (veg.) ↑Psychosocial ↑Social integration/Community participation/Organisation ↑Women empowerment (capacity building/knowledge)	↑Agrodiversity (crop, livestock) ↑Management practices (↓Agrochemical use)		Quantitative/ Qualitative	[89]

Table 1. Characteristics and outcomes of selected home gardening (HG) interventions (*Continued*).

Country	Participants/ beneficiaries	Characteristics	Economic	Social	Environmental	Pilot study	Type of measurements	Reference
Pakistan	Children (1-5 years)	Community based HG training, HNE programme w/ growth monitoring to ↑ production & consumption/utilisation of vitamin A rich produce (esp. orange-fleshed sweet potato).	↑Income/savings (potential)	↑Consumption (vit. A rich FV) ↑Psychosocial ↑Nutrition knowledge/Care practices ↓Child morbidity ↑Community participation	↑Agrodiversity (promoted crops) ×Management practices (pest control, irrigation)		Quantitative/ Qualitative	[103]
	Women	Integrated intervention, including HG (soy & vegetables), NE & cooking to improve FNS and DD.	↑Productivity	↑ Consumption (soy containing) ↑Psychosocial (attitudes) Community participation (req. for continuity)	N.D.		Quantitative/ Qualitative	[154]
	HH	Examines factors contributing to continuity of an integrated intervention, including HG (soy & vegetables), NE & cooking to improve FNS and DD.	↑Productivity/Diversification of activities ↑Income (↓poverty)	↑Consumption (FV, animal foods) ↑DD (×variety) ↑Nutrition awareness ↑Nutritional status (lipid status)	↑Agrodiversity (Intercropping, livestock) ↑Management practices (Organic fertiliser use)		Quantitative	[125]
	Gardening vs non gardening HH (women)	Examines continuity of practices. HG training & NE programme w/ community monitoring to ↑ production & consumption/utilisation (incl. cooking classes) of vitamin A rich produce.	✓ Income/commercialisation (not main objective)	↑Consumption (vit. A rich FV) ↑Psychosocial =Nutrition knowledge/Care practices ↑Social integration (sharing)	↑Agrodiversity (promoted crops) ×Management practices (pest control, irrigation, seasonality)		Quantitative/ Qualitative	[96]
Tanzania	Women (18-49 years, indirect beneficiaries)	Examine the broader nutritional effects of a HG intervention in non-participants.	↑Productivity (spillover, garden)	↑DD (Likelihood) ↑Social integration/Community participation	N.D.		Quantitative	[32]

Table 1. Characteristics and outcomes of selected home gardening (HG) interventions (*Continued*).

Country	Participants/ beneficiaries	Characteristics	Economic	Social	Environmental	Pilot study	Type of measurements	Reference
Tanzania	Mothers & children	Examines continuity of a horticulture & nutrition education intervention to↑ knowledge & care practices &nutritional status of children.	↑Productivity (# gardens)	↑Consumption (vit. A rich FV) ↑Food utilisation (solar dryer) ↑Nutrition knowledge ↓Nutritional status (retinol, parasites)	↑Agrodiversity (promoted crops)		Quantitative	[104]
USA	Low-income families	Citizen scientist evaluation of gardening project (raised bed, provision of seeds & organic agriculture training).	↑Productivity (yield) ↑Savings (food) ? Costs (✓ water/? inputs)	↑Consumption (recommended cups) ↑Agricultural knowledge ↑Social integration (sharing)	=Agrodiversity (cultural foods) ×Practices for RUE (drip irrigation)		Quantitative	[55]
	Breast cancer survivors	Mentored gardening to improve health & dietary outcomes (↓obesity & comorbidities) in a high-risk population.	? Cost-effectiveness	↑Psychosocial measures ↑Dietary attitudes ↑Consumption (FV) ↑PA ↑*Nutritional status (BMI)	N.D.	Yes	Qualitative	[58]
	Adult and child cancer survivors		N.D.	↑Psychosocial measures ↑Dietary attitudes ↑Consumption (FV) ↑PA	N.D.	Yes	Quantitative/ Qualitative	[59]
	Latino migrant worker families	Community based participatory gardening and agricultural training program to produce FV in a pesticide-free & organic way.	✓Savings	↑Consumption (FV) ↑Psychosocial ↑PA ↑Food Security ↑Knowledge (preservation) ↑Social integration/Community participation ↑Agricultural knowledge (+interest)	↓Agrochemical use		Quantitative/ Qualitative	[83]

Table 1. Characteristics and outcomes of selected home gardening (HG) interventions (*Continued*).

Country	Participants/ beneficiaries	Characteristics	Economic	Social	Environmental	Pilot study	Type of measurements	Reference
USA	Cancer survivors (≥60years)	Mentored gardening to improve health & dietary outcomes (↓obesity & comorbidities) in a high-risk population.	? Cost-effectiveness	↑Psychosocial measures/Psycho-biomarker (telomerase) ↑Dietary attitudes ↑Consumption (FV) ↑Phys. performance ↑Nutritional status (Waist circumference)	N.D.	Yes	Quantitative/ Qualitative	[60]
	Seniors	Feasibility study to explore the health & nutrition benefits of a gardening project (raised bed, provision of tools, recipes & training) in a low-income senior community.	N.D.	↑Psychosocial ↑Consumption/view of health ↑Workload (manageable) ↑Social integration (sharing, engagement) ↑Agricultural knowledge	N.D.	Yes	Quantitative/ Qualitative	[61]

↑ Improvement or higher. ↓ Decrease or lower. = No change, maintenance.? Unknown or inconclusive effect. * Trends. ✓Positive outcome. × Negative outcome. *Italics imply the outcomes were measured.* Regular font style implies the outcomes were mentioned or discussed. FV: Fruits and vegetables. PA: Physical activity. BMI: Body mass index. RUE: Resource use efficiency. N.D.: Not determined or detailed.

CHAPTER 3

The Wisdom Imperative: Peace Through Education for a Sustainable World

Sue L. T. McGregor

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Unsustainable consumption is a problem of conscience and a societal challenge thwarting a sustainable world. Morally conscious consumption is grounded in wisdom. The paper thus ties wisdom to consumption as a way to help sustain the world. After profiling wisdom as a construct, the discussion turns to conceptualizing both peace (seven types) and peace education (i.e., education about peace, for peace, and peace through education). Special attention is given to peace through education (including problem-posing education) and to wisdom and practical wisdom as avenues to a sustainable world. By experiencing a form of education that helps them learn from their accumulated consumption experiences, people can gain wisdom that can be applied to their marketplace decisions for the good of humanity. Revamping the education system so it leads to wisdom, practical wisdom, and multifaceted peace is a daunting prospect, but it cannot compare to the loss of a sustainable world.

Keywords: Consumption, peace education, types of peace, wisdom, practical wisdom, sustainable world.

3.1 Introduction

This special issue concerns a sustainable world, which is difficult to attain because of societal and environmental challenges. The Guest Editor [1] suggested using educational interventions to create paths of peace because peace helps people work together to create a sustainable world. Four lines of thinking were proposed as avenues from which to contribute to this special issue: (a) unstructured global problems, (b) problems of conscience, (c) contemporary issues and (d) interdisciplinary and transdisciplinary (TD) educational programs [1].

Unsustainable consumption is a problem of conscience (i.e., a moral sense of right and wrong). In this case, conscience pertains to a person's knowledge of themselves acting as a consumer and a human at the same time [2-3]. Unconscious consumption that is not mindful of eventual fallout is a societal challenge thwarting a sustainable world. Unmindfulness is negligence, obliviousness, and blindness to the consequences [4]. As a caveat, people can be *conscious* of their actions and still make *unconscientious* choices [5]. A common example is buying a cup of freshly brewed coffee at a coffee franchise while being fully aware of the human, nonhuman species, and environmental compromise (even decimation and death) involved in producing and distributing the coffee beans [3].

Not surprisingly, McGregor [3,5] argued that modern-day consumption is not peaceful, hence not sustainable. It leads to human exploitation, social injustice, cultural compromise, and environmental decline all of which compromise a sustainable world. Inspired by Hernandez-Aguilar's [1] call for papers, this article is predicated on the assumption that a sustainable world is more likely if people are socialized to respect conscious, mindful consumption. This can be achieved by tendering a particular educational intervention [1] specifically a unique type of peace education [6]. The result would be educated people who are wise to the fact that their personal choices (especially in the marketplace) play a pivotal role in creating a sustainable world. Anyone who is morally conscious is grounded in wisdom [7]. The author thus ties wisdom to consumption and peace education as a way to help sustain the world.

After profiling wisdom as a construct, the discussion turns to conceptualizing both peace (three types) and peace education (three types). Special attention is given to peace through education and to wisdom and practical wisdom as avenues to a sustainable world.

3.2 Wisdom

"Morality pertains to the rightness or wrongness of behaviour gauged against some agreed-to standard of conduct. Immoral means the behaviour is wrong, reprehensible (so objectionable as to elicit strong disapproval, even contempt) and bad, bad because the immoral action is below a standard of acceptable quality and causes harm or injury" [2] (p. 16). "Conscience is always defined in terms of decency and grace, dignity and honor and as conformity to recognized standards" [2] (p. 170). When someone eschews good conscience, people often respond with "How, in good conscience, could you act that way?"

If someone is *morally* conscious, they are grounded in goodwill, love, and wisdom. Moral unconsciousness has its roots in greed, anger, hatred, and delusion [3, 7]. What matters to the argument herein is that people can shift from immoral to moral consciousness when they learn to use wisdom and mindful diligence [7]. Wisdom is the quality of being wise, which refers to sagaciousness, discernment, having good judgement, and being learned and knowledgeable due to lessons learned from experiences [7-8]. Wisdom is associated with such traits as unbiased judgements, self-knowledge, ethics, common sense, and deep understanding and insights. Conversely, being unwise means acting foolishly, and devoid of good judgement or good sense. Unwiseness manifests in heedlessness, a lack of intelligence, an inability to learn from experience, and unadvisable behaviour [4, 9-10].

Nicolescu [11-12] believed that the absence of wisdom in contemporary society is the crux of modern-day problems and an unsustainable world. He called for the conciliation of technoscience and wisdom (i.e., calm a dispute using mediation). Technoscience (technological advances and the scientific method and ethos) refers to the interaction between the theoretical and the practical within contemporary scientific research and development (R&D) [13]. Technoscience is problematic for Nicolescu [12] because it privileges objectivity, the universality of science, and realism (absolutism) [13]. The "overwhelming advance of technoscience (p. 11) [is] without brakes, without values, without any end other than utilitarianism [e.g., benefit the majority]" [12] (p. 101).

Nicolescu [12] said that an immense treasure of wisdom and knowledge has accumulated over time, but that technoscience has overshadowed its worthiness and significance. Technoscience has created an unbreachable divide between science and wisdom. He called this "the abyss" [12] (p. 11), a very deep, bottomless chasm. The tension arising from this chasm (i.e., profound differences between technoscience and wisdom) must be conciliated (mediated) if people want to successfully address the polycrises facing humanity [12], crises exacerbated by unpeaceful, unmindful, and morally unconscionable consumption [3, 14].

Drawing on Kirshnamurti [15], Fisk [6] expounded on wisdom. People cannot find wisdom in books. It cannot be memorized or accumulated in one spot. Wisdom comes from the abnegation

of the self. That is, it comes from the temporary denial and renouncement of one's rights, interests, or conveniences so that one can learn by keeping an open mind. Opening one's mind does not mean everything in there falls out. Instead, an open mind is an opportunity to look inside and become aware of one's own feelings and thoughts. With an open mind, people can observe themselves, become aware of what is influencing them and how, and gain wisdom by learning from these experiences (see also Ambrosi-Randić & Plavšić) [9].

Whyborn [16] claimed that "through self-awareness – the wisdom acquired over a lifetime of self-tuning – [people can] progressively take ownership of their behavior" (para. 31). Self-learning from openminded experiences leads to wisdom [16]. As a caveat, "it is not any kind of experience in itself that leads to wisdom, but rather a decision to use that experience in a reflective ... way" [9] (p. 12). Fisk illustrated this idea thus. Rosa Park's "'uneducated' activist husband had the wisdom, gleaned from his experience in the NAACP, to encourage Rosa's peace and civil rights education" [6] (p. 187).

Yang [17] proposed that wisdom tends to develop and emerge in two real-life contexts. The developmental context entails dealing with large life decisions and managing one's life. The situational context involves addressing everyday situations by problem solving or resolving emergent crises. People learn from these experiences and become wiser. People with wisdom then become "aware of others' needs because of the difficulties they [themselves] had encountered earlier in life" [17] (p. 510). It is important that people develop wisdom because they can use it to improve other people's quality of life and help them attain life satisfaction and happiness. It does so by introducing values and morality into important judgements (i.e., discernment leading to prudent conclusions or courses of action) [9, 18].

3.3 Conceptualizing Peace and Peace Education

"Gaining life experience is crucial for becoming wise(r). In this context, education ... represents a potential contributor in wisdom development" [9] (p. 15). Four in ten (43%) people agreed that education is important to gaining wisdom [9]. Hernandez-Aguilar [1] called for educational interventions that would create pathways of peace, so people can work together to create a sustainable world. What better way to start than with peace education itself because "peace education aims to create in the human consciousness a ... commitment to the ways of peace" [19] (p. 10).

3.3.1 Conceptualizing Peace

Peace is so much more than the absence of war, violence, and conflict [19], meaning peace education can (should) be very broad and comprehensive in its approach. Groff [20-21] conceptualized seven types of peace (see Table 1) (see also Smoker and Groff) [22]. They range from peace inside a person to peace between cultures and entire civilizations. Groff [21] organized them into the (a) prevention of war and violence; (b) elimination of structural violence; and (c) maintenance of holistic, complex systems. Academic practitioners who chose to develop an educational intervention that leads to pathways of peace to co-create a sustainable world [1] must be aware of the broad scope of the peace concept [19].

3.3.2 Conceptualizing Peace Education

Peace education is predicated on the assumption (or observation) that people are creating or exacerbating conflict and violence through actions informed by their values, beliefs, attitudes, and knowledge (or lack thereof) [19]. As a caveat, conflict arises when incompatible interests and goals lead to disagreement or argument. People will always experience conflict usually daily. But they can choose to respond in one of two ways: violence or nonviolence [23]. Violence

involves behaviour intended to hurt, damage, harm, or kill someone or something. Nonviolence is the personal practice of not causing harm (or causing the least amount of harm) to anyone or anything under any conditions [3, 5, 24].

Peace education seeks to build awareness and understanding, develop mutual concern, and challenge personal and social actions thus making it invaluable for a sustainable world. Peace education will help people "create conditions and systems that actualize nonviolence, justice, environmental care and other peace values" [25] (Slide 25) (see also Vega et al.) [26]. Peace education also serves to transform the human condition by challenging and changing social structures and the thought patterns that created the present conditions. The overall intent is to eliminate social injustice, reject violence, and abolish war [25, 27].

Peace education is a practical imperative and an ethical imperative [25-26]. Pragmatically, peace education contributes to "build[ing] a critical mass of people who will demand for and address the needed personal and structural changes that will transform the many problems that relate to peace into nonviolent, humane and ecological alternatives and solutions" [25] (Slide 30). It also challenges people's belief that wars cannot be avoided and does so by helping people discern alternatives to violent reactions to conflict [25].

As an ethical imperative, peace education strives to mitigate the negative impact of violent reactions to conflict on life and well-being. This form of education teaches ethical principles including but not limited to nonviolence, justice, love, solidarity, human dignity, and a respect for nature and all life. Strengthening the common good and inculcating the unity and value of life is the mandate of "major world faith traditions, humanitarian ethics and ... indigenous spirituality" [25] (Slide 32). Peace education embraces and perpetuates this ethical imperative [26].

Respecting the practical and ethical imperatives of peace education, Fisk [6] challenged peace educators to reflect on what constitutes peace education and related pedagogy. By choosing three different prepositions (i.e., a grammatical word expressing a relation between two other words), he differentiated among (a) education *about* peace, (b) education *for* peace and (c) peace *through* education. All are important, but each one yields a different result. The preposition about means to be the topic of, the point of, or the main concern. The preposition *for* means in favour of, toward something, to be the purpose of. Through connotes the means of doing something. It also refers to a passage from one place to another, and it can refer to continuing on in time [4].

Peace *through* education is preferred because of its holistic and all-encompassing nature [6]. In her call for papers, Hernandez-Aguilar [1] had envisioned "educational interventions ... leading in general to paths of peace" (para. 1). Fisk's [6] work about three approaches to peace education is in a book titled *Patterns of Conflict, Paths to Peace* [28]. This book concerned "the discovery and careful investigation of various pathways [to peace] that promise to take the traveller over or around or through conflict to a less violent, less troubling, future" [28] (p. 9). That is, to a more sustainable world [1].

Education about Peace

When people are exposed to education about peace, they receive information, facts, and ideas about things that affect peace (e.g., social justice, conflict, human rights, equity, gender equality, tolerance, human security, environmental integrity, diversity). Learning "about something is essentially a data-gathering process" [6] (p. 174). People are not asked to challenge the social order or the status quo; instead, they are expected to uncritically accept it. This approach can also be anti-dialogical, meaning there is minimal exchange among learners with the teacher viewed as the authority figure. Sometimes education *about* peace introduces problem-solving skills. As a caveat, a thorough knowledge of aspects affecting peace should not be disparaged [6], but education about peace falls short of what is needed to build a sustainable world. Knowing *about* something and feeling compelled to *do* something is not the same thing.

Table 1: Seven types of peace [21] and attendant peace infractions in consumer context [3,5].

Types of Peace	Peace Infractions Arising from Consumer Context
Prevention of War and Violence	
Negative peace (a culture of war) is the absence of overt war and violence – no direct threat from the spectre of war. War is a state of open fighting between or within *nations*. Violence is extreme, intense force exerted for the purpose of violating, damaging, or abusing *someone*.	• Only one in six people live in a consumer society. The unlimited wants of the privileged few create conflict for scarce resources. • Corporate media and transnational corporations (TNCs) perpetuate violence under the guise of new brands and forms of entertainment. Youth uncritically consume these goods and services. A whole generation is thus desensitized to violence. • The production processes used to make more than 80% of consumer goods exploit child labour, or use sweatshops, prison labour, or slave labour. Deeply entrenched social injustice is created and local violence and civil disorder can result from these injustices.
Balance of international forces is a systems view of peace. When there is a dynamic balance between political, economic, technological, social, and cultural factors in the international system, there is peace. An imbalance in these patterns of relationships can lead to tension, conflict, strife, and possibly war and a need for the system to be rebalanced.	• Consumers buy mundane products and services from TNCs without realizing the TNCs are deeply entrenched in the military-industrial complex (MIC) (e.g., General Electric, Daimler Chrysler, Fuji). The MIC is a symbiotic relationship between a nation's armed forces and associated political and commercial interests. • TNCs making consumer products may support the arms trade and oppressive military regimes to gain trade advantages. This leads to an imbalance in international forces.
Eliminate Structural Violence	
Positive peace (structure of society) is the presence of justice through the absence of **structural violence**. The latter happen when the design of social institutions and policies creates barriers that result in lack of adequate food, housing, health, safe and just working conditions, education, economic security, clothing and protection, and family relationships. People thus affected tend to live a life of oppression, exclusion, exploitation, marginalization, collective humiliation, stigmatization, repression, and inequities. The lack of opportunities they face is no fault of their own – the fault lies with how society is structured.	• The entire marketplace infrastructure is a key source of structural violence. Nonpeaceful production and distribution methods prevail. Opportunities for consumers to buy otherwise are limited due to structural violence. Buying things inadvertently leads to oppression, exploitation, marginalization, loss of resiliency, loss of solidarity, and loss of sustainability. • Although unintentional, consumers perpetuate violence with few shopping alternatives at hand; less than 1% of global trade is *fair* trade, which supports labourers, farmers, and their communities.
Relational peace (feminist peace) is rooted in personal experiences and is unique to each person. It is peace at the individual level. When this type of peace is missing, it is experienced as violence in relationships (child and partner abuse), in the street, on the school bus, in the school yard, in the home, in the workplace, with peers (bullying), and in the community (graffiti and terrorizing).	• Parenting styles can perpetuate violence including children uncritically watching TV, advertising, or using social media. • Some youth engage in violence to obtain brand-name products. • The presence of TNCs in schools (fast food, beverages, technology) further desensitizes students to the lurking sceptre of violence associated with TNCs. • Alienation in consumer society leads to feelings of needing to belong that are ameliorated with overspending, addictions, and gang affiliation. • Pace of consumer society (work to spend) can lead to stress, depression, and anxiety, which is often mollified by spending. A vicious cycle ensues. • Advertising and marketing manipulate the collective psyche; everything is for sale, including relationships.

Table 1: (continued)

Sustain Holistic Complex Systems	
Inner peace is a holistic state of mind, body, and soul – peace within. Experienced within each person, it arises from religions, spirituality, and levels of consciousness. People who experience it say the feeling is not dependent on time, people, place, or any external object or situation. Prayer, meditation, and the mind-body connection help attain and sustain this peace.	• The consumer society is about image and illusions. People buy things to define themselves. This inner stroking sustained by spending is not sustainable and can be quite harmful. • People assume inner happiness comes from owning things and having monetary wealth. • Buying things to define oneself entails involvement in the marketplace (structural violence). • People buy things for a quick, feel-good fix instead of slowing down to reflect and feel good from self-knowledge. • People are busy *doing* instead of *being;* doing requires materialism. Lack of being (true essence and existence) diminishes inner peace.
Eco (Gaia) peace means living holistically in a peaceful, respectful relationship with and stewardship of nature, and the thousands of other species that share Earth with humans. Lack of eco peace refers to all forms of physical violence against the environment and nonhuman species leading to unsustainability, loss of diversity, and climate change.	• Most production and distribution systems pollute and extract scarce resources. • We would need seven earths to consume as people do in two countries (North America) let alone the rest of the world. • Consumer society perpetuates a scarcity mentality instead of a stewardship mentality. • Nature is seen as a resource that can be extracted and exploited instead of something to be respected, enjoyed, and stewarded for future generations.
Intercultural peace is peace between diverse, whole cultures, civilizations, and religions/faiths. People approach each other with full respect and tolerance (openmindedness) for the human needs that unite and motivate human life. People honour the rich cultural diversity of humanity. Intercultural peace is an active intercultural communication – constant, positive human interaction that sustains the whole of humanity.	• A consumer society asserts rights over responsibilities. • The powerful sense of individual consumer entitlement precludes tolerance and respect for others. • Western, top-down economic globalization suppresses other forms of globalization that privilege solidarity, gendered perspectives, indigenous knowing and such thereby preventing intercultural peace. • Economic systems are driven by the ubiquitous competitive paradigm (technological progress, wealth accumulation) leaving little room for the cooperation, mutual interest, and solidarity paradigms. Resultant negative human interaction diminishes intercultural peace.

Education for Peace

Fisk [6] then presented an interesting argument. He suggested that if education about peace (leading to more knowledge about what affects it) does not lead to "new openness or an understanding attitude on our part ... there is something more at work – something that has to do with values, moral standards or the development of our sensitivities and character" [6] (p. 180). To counter any passivity and lack of motivation to change things that can happen with education *about* peace, he proposed education *for* peace (i.e., in favour of peace), which helps people recognize that their "usual way of seeing and doing things perpetuates injustice [and a lack of peace]" [6] (p. 181).

Education for peace equips people to deal with ideologies, paradigms, worldviews, values, attitudes, skills, principles, and moral standards. They gain a sensitivity to others, an awareness of their own cultural conditioning, and they learn new perceptions that move them to take a different path than they did in the past [6]. Educating *for* something means education serves a particular reason. It orients people to achieve a specific purpose, in this case, to achieve peace. The danger with this approach is that it is based on "a hunger for certainty [and security] and a fear of ambiguity" [6] (p. 183). Education *for* peace can thus fall prey to being an ideological conversion instrument that divides people. Educators can slide down the slippery slop of proselytization (i.e., converting to another's opinion or belief) especially if the pedagogy is not dialogic [6].

Table 2: Peace through education [6].

strive for wisdom
engage in moral self-reflection
strive for self-clarity by consciously resisting dependencies on systems, authorities, political and religious leaders
commit to democratic action
live toward one's potential
be critically aware of life's conditions (the human condition)
critically resist ideals and ideologies
appreciate everyday life and every day of life
live with uncertainty and moral ambiguity couched in one's potential to flourish
accept that you do not know, which opens the door to learning
face up to cherished certainties, and be willing to question them and let them go
openly face one's limitations and conditioning and do so critically with others
dispense of preconceived notions and values for the sake of new and greater knowledge and insights
work together for larger truths by diligently verifying facts and findings, and testing new hypotheses
develop capacity for cooperation, trust, and commitment
accept that the world is incomplete, and the future is uncertain, but have faith in the possibilities of the future
engage in self-invention and not just self-discovery; respectively, what we search for does not exist *until* we find it versus something already exists and is *waiting* to be found

Peace through Education

Educate is Latin educare, 'to lead out' [8]. Fisk maintained that "education of a certain kind in and of itself is considered to be a vehicle for learning peace" [6] (p. 185). Education about or for peace would not be needed if all education inculcated certain learnings, principles, and imperatives to which people would be consistently and broadly exposed thus leading them to peace [6] (see Table 2). Through a certain kind of education, people can be lead to peace. "When the process of learning in other subject areas mirrors the substance of peace education, then we don't need to engage in peace education as a separate endeavour" [6] (p. 185).

Problem-Posing Education

Peace *through* education (see Table 2) would depend on a particular pedagogical collection: inquiry-based learning, project-based learning, collaborative learning, an issues-based approach, authentic learning, democratic education, moral development education, teaching controversial and sensitive issues; and thematic and integrative curricula [6, 19, 27].

In addition to the aforementioned peace pedagogy, Fisk [6] strongly advocated for problem-posing education as the main avenue for ensuring peace *through* education. Hernandez-Aguilar [1] was concerned about the challenges of building a sustainable world. From a problem-posing perspective, "the 'problem' [is] the world and its economic and political structures, many of them exploitive" [6] (p. 177). Problem-posing education lets people view the world as unfinished and problematic, but more important, people learn they can change the world by changing existing power arrangements. The world actually becomes "a medium or go-between in the learning experience" [6] (p. 176). "The world intercedes in our learning context and provides the opportunity to dialogue as equals about common life-situations" [6] (p. 177).

An awareness of one's own oppressed or flawed consciousness and one's social and ideological conditioning is the starting point of problem-posing education [6]. Problem posing thus requires people to be radically open to differences and diversity and to "what the world reveals about itself" [6] (p. 180). With acceptance of these revelations, "the world touches them differently because fresh assumptions or expectations allow them to perceive new realities" [6] (p. 179).

When the place where people stand and look at the world shifts, knowledge is engendered, meaning it is an offspring of the new perspective provided through problem posing [6]. This new knowledge can be transposed into wisdom [6, 9].

Education is important to gaining wisdom [9]. Fisk [6] asserted that peace through education helps people gain wisdom by providing increased awareness of both social and ideological conditioning (blinders) and cherished certainties that block the ability to deal with uncertainty. The knowledge people gain through education and their learning experience can grow and develop into wisdom [6, 9]. People can use their wisdom to help build a sustainable world.

3.4 Practical Wisdom

The knowledge gained through problem-posing education "can sometimes make all the difference in the world" [6] (p. 180) (pun intended). Learning from this knowledge acquisition process can lead to wisdom [6, 9], which must be developed if people want to create a sustainable world [16]. The latter are compromised by unconscious, unmindful consumption [3, 5] (see Table 1). That said, Whybrow [16] was convinced that "collectively we can acquire the wisdom to sustain a vibrant and balanced society" (para. 12). Supporting this supposition, consumer scholars [18] recently applied Aristotle's notion of practical wisdom to transformative, liberatory consumer behaviour that is fully focused on personal and collective well-being and, by association, a sustainable world. They were convinced that Aristotle's idea was appropriate for considering matters related to the good of humanity including consumption. They titled their work *Can Consumers be Wise*? and answered yes from two perspectives. Yes, consumers can be wise and shrewd in their marketplace behaviour thereby avoiding being taken in and manipulated by marketing hype. And yes, consumers can be wise from an Aristotelian perspective by cultivating and using practical wisdom [18].

To recap, wisdom is "the capacity of judging rightly in matters relating to life and conduct; soundness of judgement in the choice of means and ends" [29] (p. 2325). Practical *wisdom* stems from Greek *phronesis*, 'prudent, self-controlled' [8, 18]. The notion of phronesis takes us "beyond knowledge to wisdom" [18] (p. 8). Practical wisdom is a type of intelligence or wisdom concerned with the virtue of *practical thought* [18] (i.e., think hard and deep before you act).

In more detail, practical wisdom ("the master virtue") [18] (p. 665) helps people figure out the best balance between other virtues in a given context. Virtues include courage, honesty, empathy, compassion, generosity, justice, caution, decisiveness, kindness, frugality, and responsibility [18]. Should the consumer favour responsibility or frugality? Should they favour compassion or decisiveness (quickly settle an issue) when buying something? What does this particular purchase situation demand of them to ensure well-being and quality of life for all [18]?

Practical wisdom is thus defined "as developing plans and solutions that are well reasoned and capable of action in regard to matters that are good or bad for humanity" (i.e., human and earthly welfare) [18] (p. 9); that is, a sustainable world [1]. In this light, being a wise consumer is more than shrewdness, more than cost-benefit analyses or knowing one's preferences to avoid manipulation. It is instead "about perceptive, context-specific judgements with a mission to maintain or enhance [personal and collective] well-being" [18] (p. 664). These consumer judgements should be grounded in the virtue of practical thought and wisdom [18]. The resultant well-being and quality of life are profoundly connected to a sustainable world [1].

3.5 Conclusion

Hernandez-Aguilar envisioned "paths of peace" [1] (para. 1). Aristotle, through *phronesis*, envisioned "hope and direction through practical wisdom" [18] (p. 664). These two ideas go hand in hand and could be the backbone of peace *through* education [6] for a sustainable world [1].

Creating this educational intervention [1] is an imperative as McGregor [3, 5] so powerfully illustrated in her observations about the ubiquitousness of unpeaceful, unsustainable consumption and production (see Table 1). Unconscionable actions in the consumer context (i.e., problems of conscious) [1] severely compromise, nearly nullify, attaining a sustainable world. McGregor posited that "today's consumption reality is complex, chaotic and oppressive [but she remained convinced that citizens can benefit from] a new way to frame consumption" [3] (p. 148).

"To have practical wisdom is to know what to aim for, to know the purpose of being ... a conscientious consumer" [18] (p. 666]. If people can learn from critically examining their accumulated consumption experiences (see Table 1), they can gain this wisdom, which has become a global imperative. As Hernandez-Aguilar earnestly stated, if we do not attain "global sustainability [there will be reverberating] repercussions on the quality of life and survival of [humanity itself]" [1] (para. 1). One step in that direction is peace *through* education leading to the development of wisdom and transformative, liberatory consumer behaviour. Revamping the world's education system so it leads to wisdom, practical wisdom, and multifaceted peace is a daunting prospect, but it cannot compare to the loss of a sustainable world.

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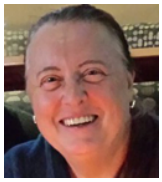
About the Author



Dr. Sue L. T. McGregor (PhD, IPHE, Professor Emerita) is a Canadian home economist (nearly 50 years) retired after 30 years from Mount Saint Vincent University, Halifax NS. She has a keen interest in home economics philosophy and leadership along with transdisciplinarity, research paradigms and methodologies, and consumer studies and education. She is a ATLAS Fellow, a Rhoda H. Karpatkin International Consumer Fellow, and she received the TOPACE International Award (Berlin) for distinguished international consumer scholar, especially as consumer educator using a transdisciplinary perspective. Dr. McGregor is the recipient of Kappa Omicron Nu's (KON) Marjorie M. Brown Distinguished Professor Award (home economics leadership) and is Docent in Home Economics at the University of Helsinki (lifetime appointment in recognition of international leadership). She published Understanding and Evaluating Research (SAGE) in 2018. Her scholarship is at www.consultmcgregor.com

CHAPTER 4

Performance Evaluation of Mechanical and Durability Properties of Fly Ash and Silica Fume Based Concrete for Sustainable Building Material

Siva Shanmukha Anjaneya Babu Padavala, Malasani Potharaju

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The intensive use of cement in construction is a significant environmental concern. To reduce the use of cement for energy consumption, the use of supplementary cementitious materials (SCMs) like Fly ash (FA) and Silica fume (SF) in concrete is an interesting solution. FA and SF-based construction materials offer a lot of potential as alternatives to ordinary portland cement (OPC) because of their high performance and environmental friendliness. The level of replacement and the necessity for additional cementitious content are critical considerations when choosing the most sustainable material for concrete production. To achieve long-term sustainability, the use of FA and SF in the construction industry is essential. Therefore, the authors attempted to identify the preferred material between FA and SF for sustainability by conducting a performance evaluation on the mechanical and durability properties of two binary mixes, i.e., FA and SF-based concrete mixes. The first binary blended concrete mix is prepared by replacing cement with FA at 20%, 30%, and 40% by weight, and the second mix is prepared with SF at 5%, 7.5%, and 10% by weight. The compressive strength (CS), flexural strength (FS), water sorptivity (WS), and rate of chloride penetration (RCP) of these two binary blended concrete mixes were studied. The results show that the incorporation of SF and FA has a significant impact on workability. The use of SF considerably increased the early and long-term strength of concrete, whereas FA lowered early age strength; nevertheless, it enhanced long-term strength. It was concluded that the SF contributed to better durability properties than FA. FA at 30% and SF at 10% exhibited the desired strength and durability than OPC, which can be used as a sustainable building material.

Keywords: Binary blended concrete, fly ash, rate of chloride penetration, silica fume, water sorptivity.

4.1 Introduction

The development of green construction materials has been aided significantly in recent decades by the construction industries, which increased sustainability demands. Cement manufacturing is

accountable for 5–8% of worldwide CO_2 emissions [1]. Concrete production releases compounds into the air and water that contribute not just to global warming, but also to various pollutants [2]. So far, there have been two key developments in finding sustainable building materials: replacing natural aggregates with recycled materials and using SCMs to partially or entirely replace Portland cement [3]. Some environmental benefits can be perceived from this perspective, resulting from a structure's resilience and the capacity to shape its environmental profile through material-construction optimization. These encourage cleaner production by lowering emissions, air pollutants, and wastes associated with mining and material manufacturing. Concrete will continue to be the most used building material; hence resource extraction in its manufacturing will continue unless more sustainable and environmentally friendly alternatives are found. The use of SCMs instead of OPC in concrete has become increasingly popular in recent years. FA is a coal combustion product used in power plants [4, 5]. ASTM C618 defines two types of FA: Class F and Class C. The fundamental distinction among these groups will be the amount of calcium, silica, aluminum, and iron content in ashes.FA chemical properties are highly influenced by coal-burned chemical substances, i.e., anthracite, bituminous, and lignite. Class F FA is used with the combination of Portland cement to form pozzolanic reactivity, for which it requires $Ca(OH)_2$. It reduces the heat of hydration, enhances durability, and also due to pozzolanic and filler action, concrete strength improves [6–9]. Compared to all other natural pozzolan materials, FA is vastly used to replace cement at high levels because of its low water requirement and excellent workability [10–12].

The use of FA as a partial substitute for cement in concrete has many advantages, including reduced greenhouse gas emissions, suitable characteristics of strength, long-term durability, reduced energy consumption, and lessening the burden on natural resources [13, 14]. The binary blended cement with a high volume of FA exhibits lower early age strength due to shallow pozzolanic reaction.

SF is a by-product of the silicon melting process. Metallic silicon and ferrosilicon alloy are rich in silicon dioxide (SiO2) which is produced from this process and consists of microscopic spherical particles. Because of its extreme fineness and rich silica content, silica fume is an impressive pozzolanic material [15, 16]. SF having large surface area and high amount of SiO2 content makes it more reactive than FA, resulting in a superior pozzolanic reaction. SF is used in two separate ways, one is to reduce the cement content, and the second is to improve both fresh and hardened properties of concrete [17, 18, 19, 20].

The utilization of different SCMs in concrete like FA, SF, Ground granulated blast furnace slag (GGBFS), metakaolin, and lime sludge can decrease the CO2 emission into the environment [21]. The use of SCMs in concrete has both monetary and execution benefits in contrast to conventional concrete. Keeping the above benefits with both FA and SF as a replacement to cement, the present research aims to identify the preferred material between these two SCMs to achieve the best performing binary blended concrete mix for achieving sustainable building material.

In the present study, binary blended concrete mixes with FA at 20%, 30%, 40%and SF at 5%, 7.5%, 10% separately as substitutes to cement were developed to study their performance at 7, 28, 90, and 180 days of age.

4.2 Materials, Mix proportions and Methodology

4.2.1 Materials

The ordinary Portland cement (Grade 53) employed in this study conformed to IS: 12269-1987, with specific gravity and specific surface area of 3.12 and 225 m^2 /Kg, respectively. The initial and final setting times are 40 and 480 minutes, respectively. The FA used in this investigation is of the class F variety and was procured from Vijayawada Thermal Power Plant Station in

Vijayawada. It has a specific gravity of 2.34 and a fineness of 320 m2 /kg. SF conformed to IS 15388–2003, having a specific gravity of 2.42, and the fineness is 20000 m^2 /kg. Fine aggregate with size range, specific gravity, and bulk density of 0.075–4.75 mm, 2.64, and 1.48 g/cc corresponds to Zone-II as per IS: 383-1970 and is fetched from a local river. As a coarse aggregate, locally accessible granite adhering to IS: 383-1970 was employed. It had a size range of 12.5-20 mm, a specific gravity of 2.78, and a bulk density of 1.52 g/cc. For curing and mixing, potable water was used. The chemical constituents like CaO, SiO_2, Fe_2O_3, Al_2O_3, SO_3, MgO, K_2O, Na_2O, LOI are 65%, 20%, 2.3%, 4.90%, 2.30%, 3.10%, 0.40%, 0.20%, 1.80% respectively in cement, similarly 2.30%, 55.59%, 9.50%, 26.64%, 0.44%, 0.60%, 0.40%, 0.23%, 4.30% respectively in FA and 1.1%, 91.1%, 1.22%, 1.3%, 0.2%, 0.4%, 0.16%, 0.15%, 4.40% respectively in SF.

Concrete Mix Proportion

M30 grade concrete was engineered without any mineral compounds as per IS 10262:2009 to achieve the required target strength. Table 1 displays the concrete design mix proportions for the chosen water binder ratio of 0.45. Here, fine aggregate of 679.32 kg/m^3, the coarse aggregate of 1130.94 Kg/m^3 and water of 171 Kg/m^3 are constant for all the mixes.

Table 4.1: *Concrete design mix proportions in Kg/m^3*

Mix	Cement	FA	SF
OPC	380	0	0
FA20	304	76	0
FA30	266	114	0
FA40	228	152	0
SF5	361	0	19
SF7.5	351.5	0	28.5
SF10	342	0	38

4.2.2 Methodologies

The methods adopted to find the different properties of binary blended concrete mixes as per IS/ASTM standards were presented. The properties include workability, CS, FS, WS and RCP.

i. Workability: The slump test is used to find the workability of concrete. As specified in IS1159: 1959 [22], it is an inverted cone of 300 mm in height, and its top & bottom diameters are 100 & 200 mm. The platform is set on a smooth surface, and the container is filled in three layers with the concrete. The mold is then carefully removed vertically; the level difference between the mold and the highest point is used to calculate the slump of concrete.

ii. Compressive strength: To test CS, concrete cubes 150×150×150 mm in size are produced. The cubes are placed in a manner to transmit load on opposite faces, as defined in IS 516–1959 [23]. The applied load is axial without any disruption, as stated in IS 516–1959 [23]. To compute the CS, the highest load applied to the specimen was recorded.

iii. Flexural strength: To test the FS, concrete prisms with a dimension of 100×100 ×50 mm are casted. The specimen is positioned in the system so that the load is imparted to the highest surface of the mold in two axes 133 mm apart. As a result, the maximum load borne by the specimen is recorded in accordance with IS 516 [23].

iv. Water sorptivity: According to ASTM C 1585 [24], water sorptivity is a test used to measure the rate of absorption of water through capillary action. The specimens were

dried at 1050C until constant weight, and then the wax was applied to three sides of the specimen, with one side allowing water to transfer from the bottom portion. Rods were positioned at bottom of the tray for support of the specimen, and water is filled in the tray to achieve a level of 1 to 3 mm on top of these supporting rods. Specimens were removed from the tray after 5, 10, 30, 60, and 120 minutes, and their weights were recorded. To get the sorptivity coefficient (S), the cumulative amount of water absorbed per unit cross-sectional area (i) was plotted against the square root of time $\sqrt{t}$. The slope of the best-fit line is then used to calculate S ($Y = a + bX$) using least-squares linear regression analysis. Where i (g/mm^2) denotes the cumulative amount of water absorbed per unit cross-sectional area of concrete specimen. S ($g/mm^2/min^{1/2}$) represents the sorptivity coefficient, and t is the time in minutes.

Where i (g/mm^2) denotes the cumulative amount of water absorbed per unit cross-sectional area of concrete specimen. S ($g/mm^2/min^{1/2}$) represents the sorptivity coefficient, and t is the time in minutes.

v. Rate of chloride penetrability: ASTM 1202 [25] specifies the casting of cylindrical specimens with a diameter of 100 mm and a thickness of 50 mm. The specimens were placed in the cells and left for 6 hours at 60 V. One compartment had 3 percent NaCl and the other 0.3 mol/L NaOH. The concrete cylinder's electrical current was measured, and the total charge passed (in coulombs) was utilised to indicate the concrete's resistance to chloride ion penetration.

4.3 Results and Discussion

4.3.1 Workability

Figure 4.1 displays the slump values of binary blended concrete mixes comprising of FA and SF. For the FA mixes, the slump value increases with the increase in FA, whereas SF mixes exhibited more or less the same slump as that of the OPC mix. This increase in a slump with FA is due to dense particle packing, which reduces inter-particle porosity leading to less consumption of water [26]. Hence it can be concluded that SF is a preferred material compared to FA as SF could able to retain the desired slump.

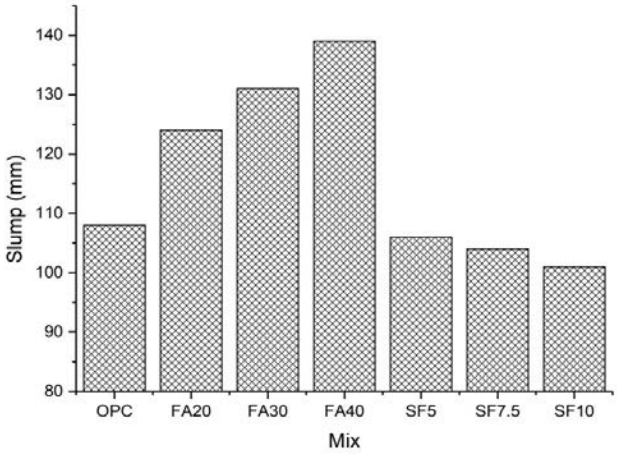

Figure 4.1: *Comparison of slump values for binary & OPC mixes.*

4.3.2 Compressive Strength

The CS of FA and SF mixes at various ages (7, 28, 90 and 180 days) are represented in Figure 4.2. The CS of SF concrete is greater than that of OPC concrete at all ages, and the gain in strength increases with the increase of SF content. However, the SF mix with 5 percent SF itself achieved the desired target strength. The interaction of reactive silica of pozzolan with calcium hydroxide (CH) produces extra calcium silicate hydrate (C–S–H) due to cement hydration [27]. As a result, the CS of the mixes containing SF was more significant than that of the OPC mix, even in the early ages. At early ages (7 and 28 days) FA30 binary blended mix had lower CS than the OPC mix, whereas at later ages (90 and 180 days), it exhibited higher CS than that of OPC mix. This low early strength is consistent with the result of M.A. Megat Johari et al. [28]. Both FA20 and FA40 binary blended concrete mixes showed lower CS than the OPC mix, irrespective of age. Hence it can be concluded that SF is a preferred material compared to FA, as SF contributes to better CS at early and later ages.

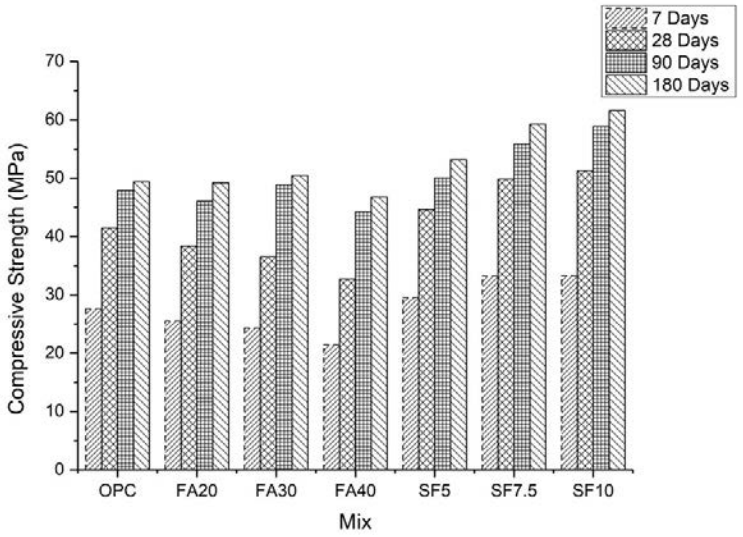

Figure 4.2: *Comparison of compressive strength for binary & OPC mixes.*

4.3.3 Flexural Strength

Figure 4.3 displays the FS of FA and SF mixes at various ages (7, 28, 90 and 180 days). At all ages, the FS of SF concrete is greater than that of OPC concrete, and the gain in strength increases as the SF content increases. The SF mix with 5% SF, on the other hand, achieved the desired target strength. The presence of SF particles fills the pores in the C-S-H gel structures while acting as a nucleus to form a strong bond with the C-S-H gel particles. FS exhibits the same trend as CS at early and later ages. FA30 binary blended mix had lower FS than OPC mix at early ages (7 and 28 days) but higher FS than OPC mix at later ages (90 and 180 days). Regardless of age, both the FA20 and FA40 binary blended concrete mixes had lower FS than the OPC mix. As a result, it can be concluded that SF is a preferred material over FA because SF contributes to better FS at both early and late ages.

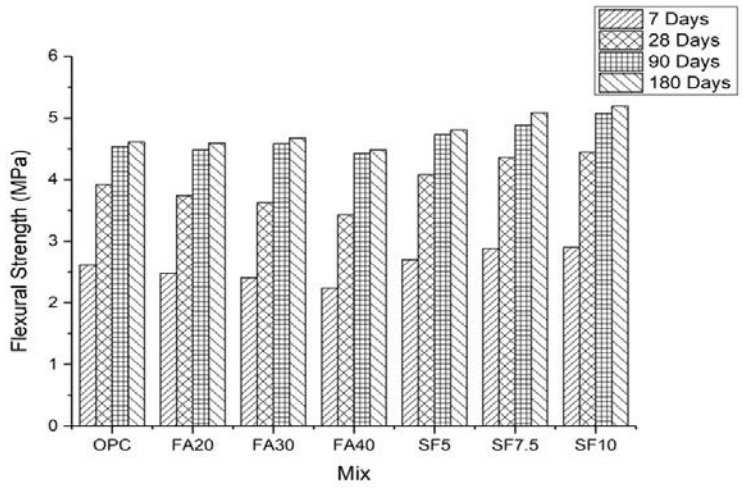

Figure 4.3: *Comparison of flexural strength for binary &OPC mixes.*

4.3.4 Water sorptivity

Water sorptivity is one of the measure of durability of concrete. The cumulative amount of water absorbed per unit cross-sectional area with time is shown in Table 2. The sorptivity coefficient is the measure of WS. From Figure 4,4, sorptivity coefficients are calculated by using least-squares linear regression analysis. Figure 4.5 displays the calculated sorptivity coefficients.

Table 2: *Cumulative water absorption results*

Mix	i, $10^{-4} g/mm^2$				
	5 min	10 min	30 min	60 min	120 min
Control	2.71	3.43	4.86	6.25	7.67
FA20	2.37	2.94	3.82	4.71	6.06
FA30	2.42	3.07	4.45	5.49	6.43
FA40	2.55	3.36	4.74	6.08	7.12
SF5	2.24	2.88	3.86	4.47	5.85
SF7.5	2.13	2.79	3.71	4.38	5.47
SF10	2.08	2.71	3.68	4.29	5.28

From Figure 4.5 it is observed that SF mixes showed lesser WS than that of OPC and FA mixes. However, the SF mix with 5 percent SF itself exhibited a significant reduction in WS. The reason for the low WS of SF mixes is because of its denser microstructure. The percentage decrease in WS for FA20, FA30 and FA40 mixes is 25%, 17%, and 7%, respectively, whereas the WS for SF5, SF7.5, and SF10 mixes is 26%, 32% and 35%, respectively compared to the OPC mix. Hence it can be concluded that SF is a preferred material compared to FA, as SF mixes exhibited lower WS.

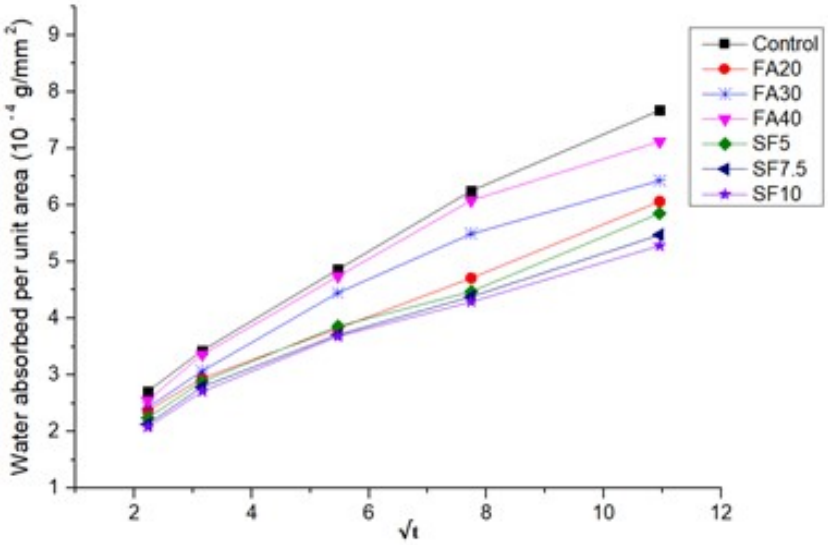

Figure 4.4: *Water absorption VS* $\sqrt{t}$.

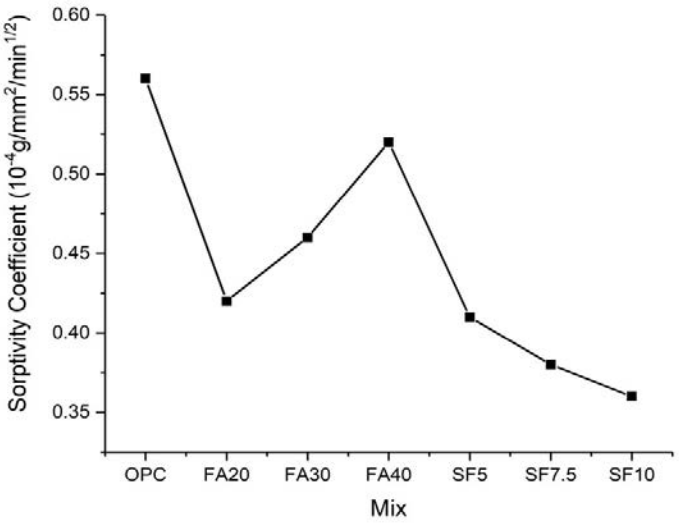

Figure 4.5: *Sorptivity coefficient results.*

4.3.5 Rapid chloride penetrability

RCP test is used to measure one of the durability property, i.e., penetrability. The charge passed is the measure of penetrability expressed as RCP. Figure 4.6 depicts the charge passed of FA and SF mixes at all ages 7, 28, 90, and 180 days. SF mixes exhibited superior durability compared to both FA and OPC mixes. SF mix with 5 percent SF itself exhibited a significantly lower

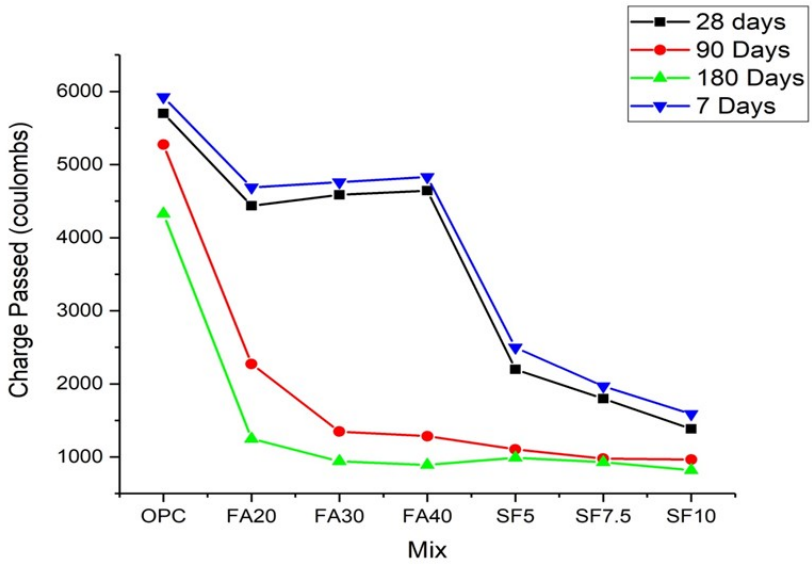

Figure 4.6: *Comparison of charge passed through binary mixes & control mix.*

RCP. The rate of chloride penetration decreased with age for all mixes. The rate of chloride penetration decreased with the increase in FA or SF at all ages except a marginal increase in FA mixes at 28 days. It was noticed that a significant reduction in the rate of chloride penetration of FA mixes at later ages (90 and 180 days). This is identical with the findings of Alireza Bagheri et al. [29]. Hence it can be concluded that SF is a preferred material compared to FA, as SF mixes exhibited lower RCP.

4.4 Conclusions

This study investigated the effects of binary mixes FA and SF on CS, FS, water sorptivity, and rapid chloride penetrability. Based on the above discussions, the following conclusions can be drawn.

The workability of FA mixes increases with the increase in FA, whereas SF mixes exhibited more or less the same workability as that of OPC mix. Therefore, SF is a preferred material compared to FA as SF could able to retain the desired slump.

The CS of SF concrete is greater than that of both FA, and OPC mixes at all ages, and the gain in strength increases with the increase of SF content. The gain in CS of SF mixes was more significant at early ages.

Therefore, SF is a preferred material compared to FA, as SF contributes to better CS at early and later ages. SF mixes showed lesser WS and RCP than OPC and FA mixes. Therefore, SF is a preferred material compared to FA, as SF mixes exhibited lower WS and RCP.

Within the experimental results, it can be concluded that SF is a preferred material compared to FA as the SF binary blended concrete mixes showed superior performance in terms of strength and durability. Though all SF binary blended concrete mixes performed well, it was noticed that the SF mix with 5 percent of SF itself exhibited the desired strength and durability which

can be used as a sustainable building material. Using FA and SF is an effective way to make concrete much more sustainable with less impact on the environment and energy and reduces CO_2 emissions.

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About the Authors

Siva Shanmukha Anjaneya Babu Padavala, currently pursuing his PhD and received an M.Tech degree in Structural Engineering & Natural Disaster Management from GITAM University in 2014. His major area of research interest includes Sustainable Concrete, Recycled Aggregate, and the study of different blended materials in Concrete.

Malasani Potharaju, currently working as a Professor in Department of Civil Engineering, GITAM Deemed to be University, Visakhapatnam, Andhra Pradesh, India. His major area of research interest includes Behaviour of Concret at High Temperatures, Geo Polymer Concrete, Multi Blended Concrete Mixes, Recycled Aggregate Concrete.

CHAPTER 5

Educational Intervention Model for Lentil Consumption: A Strategy that Contributes to Sustainable Development

Yoliztli Cecilia Torres Tenorio, Claudia Hernández Aguilar, Efraín José Martínez Ortíz

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It is necessary to propose educational interventions in the population due to economic, social, and environmental situations. Thus, in this research, a transdisciplinary model of an educational intervention to increase lentil consumption was proposed. The population was known based on their lifestyle characteristics, health, and pro-health habits, including lentil consumption. The types of lentils marketed in the Mexico zone were investigated and characterized in terms of their quality attributes: sanitary, physical, and saponins, choosing the best option. Lentil-based foods were formulated to teach their preparation and sensory evaluation preferences. As part of the intervention strategy, food dishes were formulated. The training was provided in their preparation and awareness was raised about the importance of lentil consumption for sustainable development. The changes of the participants were evaluated, and they indicated that their changes were mainly attributed to economic aspects, health reasons, and care for the environment. The lentil dishes were accepted by the focus group.

Keywords: Educational intervention, model TD, sustainable development, Lens culinaris.

5.1 Introduction

In 2016, the UN established the international year of pulses, to raise awareness of the nutritional benefits as part of sustainable food production (Rios Castillo, 2018) [1]. Among the legumes with a lower glycemic index besides chickpea is lentils (Becerra-Tomás, 2017) [2]. However, in some countries, its consumption was reduced during the pandemic (Pye et al., 2021) [3]. Despite the fact that it would be a suitable food product in the face of the cormobilities that were associated with severe cases of COVID-19 disease (Valdes, 2020; Aquino-Canchari et al., 2020) [4, 5].

This pandemic made evident the need to continue joining efforts in a world in crisis, with declining living standards for some people in some countries, added to the pain that has enveloped so many families because of the losses and the way in which the death occurred. (Perkins, 2021; Sarkis, 2020; Egger et al., 2021) [6, 8]. In relation to available or excess food, we still have a world where two extreme problems persist: malnutrition and overweight and obesity (Domínguez-Hernández et al., 2022; Rue et al., 2017; Tanumihardjo, 2007) [9-11]. In the case of children, statistics show that 150 million children are underdeveloped in height and physical structure.

However, approximately 40 million are overweight. The 2030 agenda has zero hunger, food security, sustainable agriculture, and health as part of its objectives. In this sense, promoting consumption of healthy foods among the poor, diabetic, malnourished, and obese population is relevant (Nabarro, 2020; Colglazier, 2015; Boto-Álvarez, 2020) [12-14]. It is necessary to be aware and assume responsibilities, for example, the one that each of us can take in relation to our lifestyle for health. In the case of children, the fathers or tutors be responsible of them for developing nutritional resilience in the face of current and future viruses. In this way, the variety of food is important. This situation was affected in the pandemic in diverse populations and economic levels (Robayo et al., 2022) [15]. Despite the various reasons why it is convenient to consume legumes, intake in Mexico is less than the recommended 1.5-2 servings per day (1 serving = 1/2 cup) (Monge et al., 2019) [16].

Lentil (*Lens culinaris*) consumption in recent years has decreased, and the consumption of other products has increased (this for the population that can access them). INSP (2016) [17] indicated that the adult population consumes lentils, but in urban population and young people this consumption decreases considerably (Monge et al., 2019; INSP, 2016; Gutiérrez et al., 2013) [16-18]. Although in this pandemic season consumption has improved, it still does not meet the necessary requirements for each person.

A critical problem in the country is diabetes, which has one of the highest percentages of diabetic population in the world. In addition, the population needs to educate or re-educate itself to prevent, and or control glucose. By exercising and consuming low glycemic index foods (Carcavilla, 2009). Educating or re-educating the population is of interest to improve the quality of life of society, improve the environment, and the respective economic impact that these actions may have in a changing society and having to adapt to pressing situations, such as the changes left by the pandemic. Some authors point out the importance of promoting legume consumption, thus educational interventions are relevant (Wang et al., 2011; Balázs et al., 2021). The objective of this research is to establish a transdisciplinary model to carry out an educational intervention in a focus group belonging to the area of high valleys in Mexico, raising awareness of the need to change decisions and attitudes for the benefit of oneself, others, and the environment. Changes in human actions should continue to be promoted by the academy since many of them could be detrimental to everyone's life. The consumer benefits may be due to the consumption of lentils, but it has multiple benefits. In the environmental dimension, it could have as well. Among others, is that by consuming lentil protein, meat consumption could be reduced.

It is well known that human decisions and, consequently, human actions produce excess emissions of gases into the atmosphere, which are considered pollutants. Generating an impact on the environment measured through the ecological footprint (De la Torre, 2016) [22], to be aware of the damage done with the actions performed and can prevent affectations (Castillo, 2007) [23].

One of the human activities that generate a significant environmental impact and damage sustainable development is the industry. As it is known, in this industry several transformation actions are carried out, converting raw materials into products (Cardoso et al., 2020) [24]. This human activity is classified according to the type of raw material to be transformed. In the food sector, we have the meat industry, which has 30% of the terrestrial surface destined for its development and production (ONU, 2016) [25].

On the other hand, there is the agricultural industry, which occupies 40% of the surface area (OECD-FAO, 2019) [26], where 70% is destined to the planting of fodder. It is estimated that 11% of the emissions come from this industrial activity. However, 2/3 of the emissions in this sector are a consequence of the planting of fodder for livestock feed (Carmona et al., 2005) [27].

The meat industry produces gases such as CO_2 (9%) and CH4 (20%), which are classified as greenhouse gases according to the UN (Cuatecontzi and Gasca, 2004) [28]. It is important to consider that the more red meat consumption, the more production is required in the meat industry. Consequently, the environmental impact also increases (Costantini et al, 2018) [29].

Due to the above, it is important to consider food alternatives to red meat.

Red meat consumption is related to several factors. Some people indicate that the preference and high frequency of consumption of red meat is related to the ease and variation of existing dishes (Vilaboa-Arróniz et al., 2009) [30]. Other authors indicate that high consumption is related to the taste and flavor that it generates (Taddei et al., 2012) [31]. However, despite the above, the complexity that exists in the consumer's perception and his or her possibilities of acquiring it for regular consumption depends on several factors (Troy and Kerry, 2010) [32], such as economic level, and cultural aspects, dietary habits.

In general, people are taught the habits and eating styles at home and later at school. In this, the children have their approach to information about foods, identifying and knowing them from a nutritional point of view (Borges et al., 2015) [33]. Although nutrition education varies among countries. In some countries, nutrition and health care are taught in school. In underdeveloped countries, which also have different economic levels, do not have nutritional education and there are several consequences related to diseases. Therefore, educational interventions are required in various dimensions such as food, health, environment, etc. to help sustainable development. In addition, it is necessary to raise awareness of what we eat and the environmental impacts they cause. Awareness of the impact generated by the planting, harvesting and/or production of food.

In this way, it is necessary to carry out educational interventions related to food, the environmental impact of producing it, the cost, the way to prepare dishes, and the benefits that could be obtained. In this sense to lead to changes in habits that improve their own health and that of their ecosystem. In this research as a strategic food for sustainable development, lentils, and their sprouts are proposed as an option to teach the population to adopt changes in eating behavior to decide on this type of food, given their nutritional properties and low environmental impact.

Lentils have an important nutritional contribution for the benefit of the consumer. In countries with micronutrient deficient population, low economic resources and health problems related to food would be a viable option (Hernández et al., 2017; Meléndez-Sosa et al., 2020; Hernández et al., 2020) [34-36]. It is worth mentioning that not all deficiency is linked to malnutrition, but can also occur in obesity, since "hidden hunger", as this deficit is known, is not related to excess or limited food intake, but to the quality ẏ quantity of food (Hernandez et al., 2010; Cintrón et al., 2012) [37, 38].

In view of the points mentioned above, the consumption of legumes has become relevant nowadays due to their nutritional value and medium glycemic index, mainly green legumes (Rebello et al., 2014) [39]. Legume seeds contain a high concentration of protein (15 to 45%), followed by carbohydrates (25 to 60%), oils (7 to 20%), and crude fiber (3 to 15%) (Maya et al., 2013) [40]. In the case of lentils, the presence of antioxidants such as polyphenols (Silva et al., 2010) [41] promotes the proper functioning of the immune system. These could contribute to the reduction of health problems such as diseases related to metabolic syndrome and cancer (Curran, 2012) [42], if they are consumed in an adequate amount. In this sense, there are several dimensions of sustainability that make it necessary to promote educational interventions for lentil consumption.

5.2 Methodology

The present research is a longitudinal, non-probabilistic study with a sample of 53 people and a focus group of 10 people for convenience.

5.2.1 Educational Intervention Strategy

In order to carry out an educational intervention related to increasing lentil consumption as an option to sustainable development, a model was developed for such intervention (Figure 5.1).

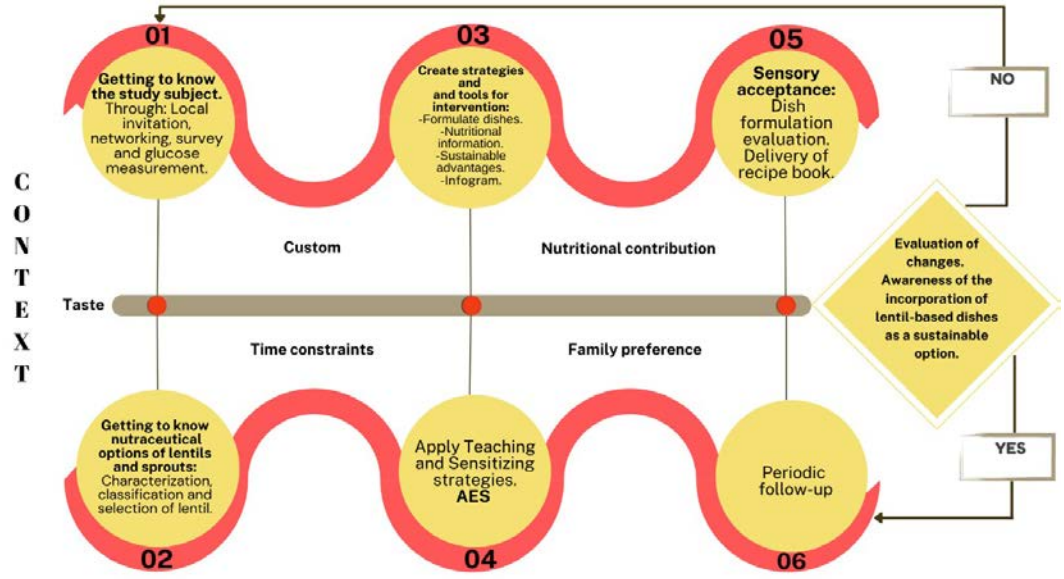

Figure 5.1: *Educational intervention model for lentil consumption based on a transdisciplinary approach [43].*

The model is built based on the transdisciplinary methodology [43], starting by getting to know the subject of study through field research using the survey as an evaluation instrument. In this way, general information is collected, as well as lentil consumption preferences. The frequency of consumption of lentils and certain foods is also collected in the survey. Finally, the physical activity they perform per week and their state of health.

The information obtained in the survey includes the e-mail, which is a means of contact to make an invitation to the activity that is related to the knowledge of their glycemic response according to their usual diet. They are provided with the general information and objective of the educational intervention, as well as the objective and the process to follow their blood glucose monitoring during the period of one week considering the food menu they consume during that period. The glucose monitoring participants were provided with a glucometer and a monitoring manual. This was to make them aware of the glycemic response after consuming their food, according to their common diet.

In step 2 of the model, it is intended to know the lentils and sprouts as a nutraceutical option. This is achieved according to the information that is investigated in relation to lentils, which allows knowing the physical characteristics and nutritional properties of different varieties of lentil seeds, such as roundness index, volume, density, wet weight, dry weight, germination, nutrients, and saponins. The resulting information is used to select the lentil varieties with the best characteristics for purchase and consumption. In this research, the classification is made by means of principal component analysis.

In the third aspect of the model, strategies and tools are created to carry out the educational intervention. In this stage, the dishes, recipe manual, and Infogram are formulated with important information on lentil consumption: economic, sustainable advantages, and nutritional contributions and its environmental impact compared to meat consumption. Proposals for lifestyle changes are also incorporated. In this way, a local invitation is made via social networks to the population where the importance of eating habits and physical exercise in their lives for

the optimal development of their lives is mentioned.

In the next point (4) the educational strategy is applied to the test subjects, knowledge is communicated, and awareness is raised. Lentil-related information is shared and contained in an infogram that is provided to the participants along with the results. As well as the lentil-based food options are presented, the nutritional data of the formulated foods are provided, and the participants are taught how to prepare them and to become aware of their consumption due to the possibility of reducing the impact on the environment. It is proposed to consume lentils as an option to reduce the consumption of meat and thus the environmental impact or simply to avoid nutritional deficiencies due to lack of protein and improve their health, highlighting the importance of moderation in the consumption of foods that have a medium and high glycemic index.

Subsequently, in step 5 (Figure 1), the tasting of food products with the proposed formulations and their sensory analysis are carried out. The participants are provided with the control dishes (meat-based) with which the lentil-based dishes will be compared. This is so that through their senses they can verify if the lentil-based dish presented is acceptable and preferable to them, using the hedonic scale for the evaluation.

In addition, we continued to provide nutritional knowledge and to sensitize the subjects investigated about the importance of lentil consumption.

A survey was applied to know the frequency of consumption that they would have after the knowledge and awareness were acquired. Afterward, step (4) was retaken, and the lentil-based food recipe booklet was provided. All the above with constant dialogues where doubts are solved. Finally, we propose to evaluate the changes in habits and the introduction of lentil consumption in their daily lives. If the participant has accepted, learned, and become aware of the importance of lentil consumption, we continue with the follow-up strategy (6) to ensure that over time he/she remains motivated and enthusiastic. However, if the participant needs to continue teaching, raising awareness, and providing information, we return to step 1 of the model. It should be noted that the follow-up of participants is a strategic point for them to maintain their adopted habits over time. It is therefore proposed that follow-up, cooperation, teaching, and motivation groups be formed.

5.2.2 Knowledge of the Subject of Study.

Field research with community members was conducted. A survey on eating habits and tastes, as well as exercise and life routines, was applied. All the above is necessary since the objective is to know (through a first approach with the population) the health situation of the subjects to be investigated. Fifty-three people participated in the survey and were asked to send a formal invitation for the following activities that are part of the educational intervention.

In the application of the educational intervention model, a focus group of 10 test subjects was formed. Of which 2 were men (between 35-40 years old) and 8 women (2 between 15 and 30 years old, and 6 between 30 and 60 years old) (see Table 1). The weight and height of the participants were determined using scales and tape measures and from which it was possible to obtain the body mass index (BMI) according to equation 1 and the basal energy content (eq. 2 and 3) (Calleja et al., 2012 and ISSSTE, 2018). As part of the knowledge of the participants, information was also obtained about their conditions, medications taken, and foods consumed which were classified by their glycemic index.

$$BMI^* = \frac{\text{Weight(kg)}}{\text{height(m)}^2} \quad (1)$$

Woman 9.99*Weight (kg) + 6.25* size(Height-cm)-4.92* age (years)-161 (2)

Man 9.99*Weight (kg) + 6.25* size(Height-cm)-4.92* age (years)+ 5 (3)

5.2.3 Characterization, Classification and Selection of Lentils.

Characterization of Lentils

Fifteen varieties of lentil seeds commercialized in the municipality of "El Marqués" in the state of Querétaro were used. Of these varieties, 10 were acquired in supermarkets and 5 are marketed in bulk.

Physical Dimension

The tests carried out for lentil knowledge were roundness index, lentil weight, density, and germination.

Roundness index (RI) was obtained from eight replicates of 10 seeds each, to which the equatorial diameter, polar diameter, as well as thickness of these were measured by using a vernier. Dry weight of lentils was determined from 4 replicates of 100 seeds each, placed in aluminum baskets and then dehydrated in an electric oven for 12 hours at 100 °C. Lentil density was obtained from the initial weight and the volume obtained: $\rho = m/V$ (Raviolo et al., 2005) [44]. Volume was obtained by a test tube; the water differential when the seeds were placed at the bottom was measured and used to determine the density (Ortega et al., 2010) [45].

The germination test was performed under two conditions: environmental and under cold stress (at 1°C) for a period of 8 days, which consisted of placing 40 seeds in Petri dishes with moistened blotting paper. Under a randomized complete block experimental design with four replications. Daily monitoring was carried out by counting germinated seeds. Finally, on the last day of planting, seedling length and fresh weight were measured. In an electric oven (Crownful with a capacity of 17.98 lt, weight of 11.34 kg), the seedlings were dehydrated at 60°C for 24 h.

Saponins

The method used to measure the amount of saponins was according to the foam quantity method (Zamora et al., 2010) [46]. This consisted of measuring the foam generated by the extracts of each of the lentil varieties (5 varieties were selected for their attributes: protein, low carbohydrate levels and affordable cost). The raw lentil was first soaked for 30 min in distilled water for 25 g of lentil, then the lentil seed soaking water was filtered. The filtered water is then placed in a test tube, shaken vigorously for 30 s, and left to stand for 15 min. Finally, the height reached by the foam is measured.

5.2.4 Strategies and Tools for Intervention

Formulation and Nutritional Information of Food Products

Four food products were prepared: two based on lentils (Lentil Bolognese and Lentil Ceviche) and two based on meat (Beef Ceviche and beef Bolognese - controls). The formulation of each food product was established (Table 1), and the nutritional value was calculated according to the table of equivalents (Table A - Annex).

Color

The color of the different food products (meat and lentil-based dishes) was determined with a handheld colorimeter (FRU WR-10QC, China). The color parameters corresponding to the CIELAB uniform color space (L*, a* and b*) were obtained directly from the instrument. L* indicates lightness (100=White and 0=Black), "a" indicates greenish-reddish [negative (-a) (green) to red (+a) (positive)] and "b" indicates blue-yellowish [negative (-b) (blue) to yellow (+b) (positive)].

Table 1: Formulation of the 4 dishes made

Ingredients	T0	T1	T0*	T2
	%	%	%	%
Lentils	0	20.66	0	24.64
Salt	2	0.41	0.29	0.49
Pepper	2	0.41	0.29	0.49
White onion	9.05	16.53	11.63	24.63
Tomatoes	21.05	41.33	29.07	49.26
Garlic	0	0	0.58	0.49
Chopped mango	22	20.66	0	0
Ground beef	0	0	58.14	0
Shredded meat	43	0	0	0

Infogram: Advantages of Lentil Consumption

The purpose of the Infogram is to provide information about lentils to the population in a didactic way. Three dimensions of information was relevant: a) the environmental benefits of lentil consumption, b) the cost and c) the nutritional contribution. In addition to this, a manual of recipes and other information was prepared.

5.2.5 Apply Strategies: Teaching and Sensitizing

The objective of this educational intervention was to present the benefits of lentil consumption compared to animal protein consumption, due to its impact on health, the economy, and the environment. The study population were people living in the Los Encinos subdivision in the municipality of El Marqués, Querétaro. It has 49 condominiums with approximately 99 houses each, making a total of 4,851.

5.2.6 Sensory Analysis

The objective of the analysis is to know the sensory preferences of food products formulated with lentils and animal protein. In addition, information was obtained regarding the lifestyle of the participating population. In this sensory analysis, the hedonic scale (Hernández et al., 2021) [47]. was used, with which the participants evaluated the characteristics of these food products using their senses (smell, taste, touch, and sight). The parameters evaluated are chewiness, appearance, flavor, odor, taste, digestive process, and nutritional contribution.

Evaluation of Possible Changes in Lentil Consumption

In this section of the model, an evaluation of the population participating in the educational intervention is carried out. The purpose is to determine whether there is any change in awareness of the benefits of lentil-based dishes, their preference, and frequency of consumption.

5.2.7 Periodic Follow-up

The follow-up to the population participating in the educational intervention consists of offering support in the preparation of dishes, as well as in the feedback of the information provided with

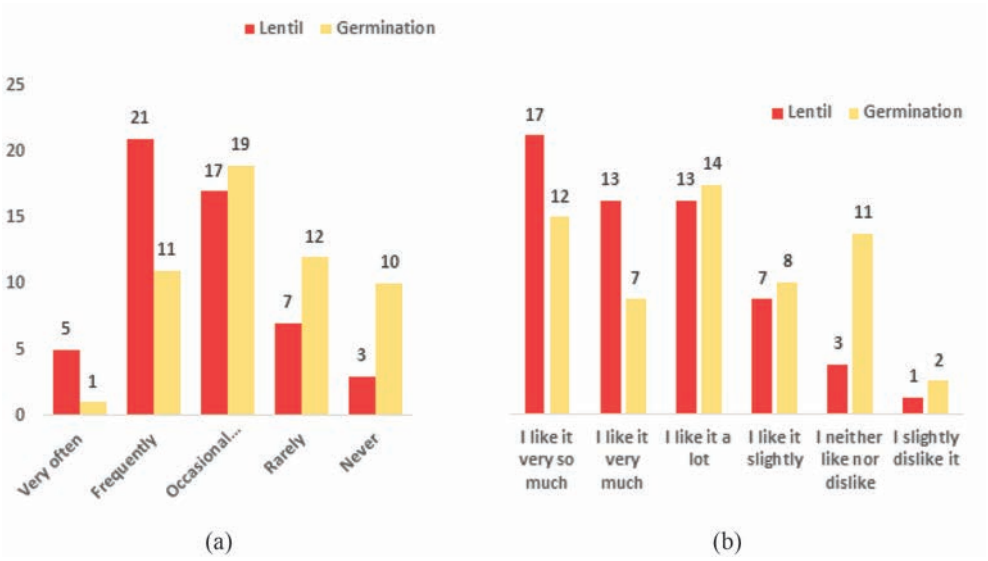

Figure 5.2: *Results of the survey applied to the population a) Frequency of consumption of lentils and sprouts, and b) Consumption preferences.*

the purpose of increasing the frequency of lentil consumption, providing encouragement and motivation. Create a group that generates a space for the exchange of experiences, etc.

5.3 Results and Discussion

5.3.1 Field Research

According to the results obtained through the field research with the 53 participants, data were obtained regarding the monthly frequency of lentil consumption, as well as the consumption of lentil sprouts and their taste for them. The results are shown in Figure 5.2, where it is indicated that the consumption of lentil seeds is higher than the consumption of sprouts (Figure 5.2a). Likewise, people have a greater taste for lentils than for lentil sprouts. Likewise, people do not have the culture of germinating seeds in general.

For 21 participants the consumption of lentil seed per month is frequent, while for 17 of the 53 participants mentioned that their consumption is occasional. However, only 11 participants mentioned that they consume lentil sprouts frequently. Figure 2b shows that 17 people out of 53 participants indicate that they like lentil seeds very much, while in the case of sprouts; 13 indicate the same level of liking.

In general, from this first approach with the population, it was observed that, of the 53 participants, 26 indicate frequent consumption of lentil seeds per month. While only 12 people consume sprouts frequently. On the other hand, in relation to preferences, 43 of the 53 indicated that the taste for lentil seeds is quite high, while a smaller number of people indicated a taste for lentil sprouts.

Table 2: Characteristics of focus group

Research subject	Sex	Age years	Disease	Weight (kg)	Heigh (cm)	*BMI	Waist (cm)	Calories maintain weight Kcal/día	Calories lose weight Kcal/día	TMB	Medication	Average glucose 30 minutes after consuming food
S1	M	41	Possible diabetes	86	165	31.6 (obesity 1)	93	2,029	1,826.00	1,790	None	191
S2	F	54	None	55	161	21.2	75	1,547	1,425.00	1,219	None	123
S3	F	15	PCOS and insulin resistance	74	164	27.5 (overweight)	90	2,369	2,095	1,590	metformin 500 mg c/12 horas	100
S4	F	60	Hypothyroidism and fatty liver II.	75	155	30.8 (obesity 1)	112	1,509	1,399	1,372	Eutirox 75 mg.	141
S5	F	29	None	49.5	158	19.5	61	2,029	1,684	1,278	None	101
S6	M	36	None	108	168	38.27 (obesity II)		2,500	2,100	2,141	None	156
S7	F	40	Hypothyroidism and PCOS	75	158	30 (obesity I)	100	1,766	1,501	1,471	Metformin 500 mg c/12 h.	125
S8	F	35	None	50	149	22.52	65	1709	1,448	1,239	None	115
S9	F	34 años	fatty liver I.	75	174	24.8	88	2,335	2,000	1,519	None	123
S10	M	34	Triglycerides 159 mg/dl	73	90	29.9 (overweight)	80	2,658	2,259	1,933	None	107

PCOS: polycystic ovaries. BMI: Body mass index.

5.3.2 Knowledge of the Subject of Study

Table 2 shows the characteristic results obtained from the intervened study subjects (focus group). Of which 4 are in the normal BMI range. However, 2 are overweight, 3 have type I obesity and one participant has type II obesity. In health subjects, 7 of the 10 participants present a metabolic condition related to eating habits. In the last column we have included the glucose of the participants taken half an hour after having consumed food in their common daily life.

Table 3 served as a support to locate whether people had diabetes, prediabetes, and no diabetes. Comparing the findings found in the population studied and the data provided by the CDC, it was found that 6 of the 10 subjects investigated presented levels that indicated to consider a possible pre-diabetes. This may be related to insulin resistance (Pollak, 2016) [48]. Therefore, people should consume foods with a low or medium glycemic index, such as lentils. Thus, the participants were recommended to visit their physician and perform the pertinent studies to confirm or rule out any diagnosis related to blood glucose levels. They should also be alert to their eating habits. The educational intervention can serve as a support to detect the possibility of preventing diseases to the extent that people become aware of and make decisions about the habits they follow.

Table 3: Blood sugar levels (mg/dL) - (CDC, 2019) [49].

Health condition with respect to blood sugar level.	Fasting glucose levels (before consuming foods)- (mg/dL)	Glucose levels 2 h after food consumption. (mg/dL)
No diabetes	≤ 99	≤ 140
Prediabetes	100 a 125	140 a 199
Diabetes	≥ 126	≥ 200

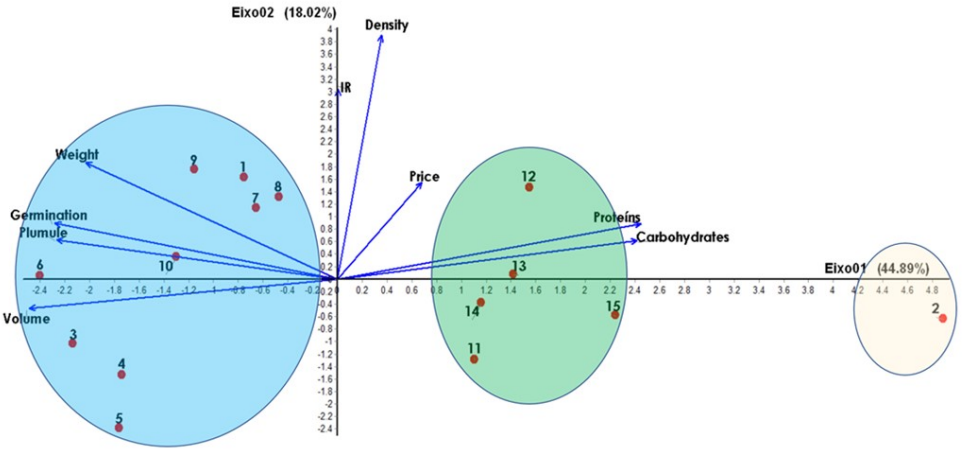

Figure 5.3: *Principal component analysis of the 15 lentil seed varieties evaluated in this research (density, Price, proteins, carbohydrates, weight, germination, plumule, and volume).*

5.3.3 Characterization of Lentils

Physical Dimension

Figure 5.3 shows an analysis of the main components of lentil seed (according to the 15 varieties studied and the characteristic attributes of density, protein, germination, volume, weight, price, carbohydrates, plumule size and IR). Three clusters were observed (I. 1,3,4,5,6,7,8,9 and 10; II 11,12,13,14 and 15; III 2). The grouping of the 15 lentil treatments into 3 clusters is due to similarities in characteristics. For cluster I the lentil varieties have similar characteristics in: Weight, germination, plumule and volume. In group II, proteins and carbohydrates are the characteristics that are similar. Finally, in group III is lentil variety 2 whose characteristics are different from the rest of the varieties.

It is possible said that there is a positive correlation for group II for the variables of protein and carbohydrates of lentils and for group III, there is a positive correlation for the variables weight, germination, length of plumule and volume of lentil. The lentil varieties that are part of

group II, of which it is agreed that they have affinity between protein, carbohydrate, price, and density. Density is a good indicator of grain quality, Ebru (2008) [50] mentions that the apparent density of lentils is 0.818g/cm^3 and the density obtained in this work was around 1 g/cm^3, so it can be deduced that the quality of the lentil is acceptable, it may be that the storage is adequate or that it has been stored for a short period of time.

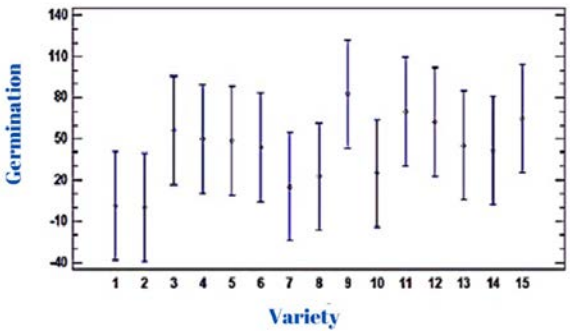

Figure 5.4: *Germination in 15 varieties of lentils.*

Germination

The 15 lentil varieties were set up to carry out the germination process under stress conditions. This means that the lentil seeds were subjected to different temperatures for periods of time. Figure 5.4 shows the results of this process showing a significant difference between varieties 1 and 2 with the rest of the varieties, the latter showing a lower germination percentage. Varieties of Lentil (9: 3, 4, 5, 6, 9, 11, 12, 13, 15) show a higher germination percentage ($\geq$ 80%).

Saponins and Lentil Selection for the Elaboration of Food Products

Based on the knowledge obtained about the 15 lentil varieties, cost, and nutritional intake (carbohydrates and proteins), the most suitable varieties to be consumed by the population were selected (Latham, 2002) [51]. Five varieties were selected whose behavior is similar and suitable for consumer consumption and purchase (See Table 4).

Table 5 shows the comparison of means of the foam column heights obtained in the saponin test. The higher the column height, the higher the saponin content. Of the 5 varieties in the three lentil conditions (1. raw, 2. raw and turmeric, 3. cooked) it was found that the raw and raw lentil conditions added with turmeric have significant statistical differences ($p < 0.05$) when compared between varieties. In the case of raw lentils and lentils added with turmeric, lentils 6 and 7 had the highest column height with respect to the other lentils. It is important to mention that the addition of turmeric to lentils reduces the saponin content. Therefore, in addition to providing phytonutrients, it also reduces the saponin content. This is convenient for people intolerant to legumes, due to the inflammation produced by saponins. In the present investigation, in the case of lentil 7, it was reduced by more than 50%.

Thus, the type of lentil selected to prepare food products is the variety 7 (Table 6).

Table 4: Selection of 5 varieties of lentils in relation to certain properties (protein, cost, and carbohydrates), for the preparation of food products.

Varieties	RI*	Density	Weight 1000 g	Cost (500 g)	Protein 100 g	Carbohydrate 100 g	Germination
4	1.01	1.01	30	21.9	9	22	91.25
5	0.94	1.01	30	13.25	9	12	95.62
6	1.01	1.31	40	14.5	9	12	90.00
7	1.24	1.17	30	17.9	21	18	96.25
8	1.05	1.39	40	20.85	23	35	97.50

*RI: Roundness Index.

Table 5: Statistical results of saponin determination.

	Response variable		
Treatment	Fch (cm) Raw lentil	Fch (cm) Raw lentil with turmeric	Fch (cm) Cooked lentil
4	$0.26^{b} \pm 0.153$	$0.16^{b} \pm 0.115$	$1.16^{ab} \pm 0.289$
5	$0.36^{b} \pm 0.231$	$0.10^{b} \pm 0.000$	$1.00^{b} \pm 0.000$
6	$1.23^{a} \pm 0.252$	$0.36^{a} \pm 0.115$	$1.66^{a} \pm 0.577$
7	$1.33^{a} \pm 0.577$	$0.23^{ab} \pm 0.115$	$1.16^{ab} \pm 0.289$
8	$0.56^{b} \pm 0.115$	$0.10^{b} \pm 0.000$	$0.90^{b} \pm 0.173$
C.V.	34.231	49.97	29.172
Significance	0.0024**	0.0453*	0.1588ns
Media	0.753	0.193	1.18
LSD	0.4855	0.1819	0.6481

Means ± standard deviation with different letters in a column are statistically different ($p<0.05$). LSD (LSD: Least Significant Difference) (LSD, a=0.05), C.V.: Coefficient of Variation. Significance: ns; indicates no significance; *: indicates significance; **: high significance.
Fch: foam column heights

Tabla 6: Characteristics of selected lentils

Variety	Cost 500 g ($)	Protein 100 g	Carbohydrate 100 g	Germination (%)	Saponin
7	17.9	21	18	96.25	Lesser amount of lentil grain.

Table 7: Presentation of formulated food products, color and saponins.

Food products	Name	Color			Saponin (measurement of foam-cm)
	1. Beef ceviche (T0)	L*	a*	b*	0
		54.48	4.30	24.51	
	2. Lentil ceviche (T1)	L*	a*	b*	0.2
		54.75	8.81	24.71	
	3. Beef Bolognese (T0*)	L*	a*	b*	0
		74.06	3.28	16.25	
	4. Lentil Bolognese (T2)	L*	a*	b*	0.1
		59.69	6.19	25.38	

5.3.4 Create Strategies and Tools for Intervention

Formulation of Food Products

Table 7 represents the image of the food products obtained, the name of the dish, the color in the dimensions (L*, a*, b*), and the saponins. The color is related to the nutritional content of the dishes. It is possible to observe that lentil-based foods have a higher value of the color dimension a*. According to the literature, a positive value of a tends to a reddish color (Hernandez et al., 2022) [52]. So, meat-based dishes have lower reddish color intensity. Yellow, orange, and reddish colors are related to carotenoid content. In this research, there is a higher value of a*, so there would be a higher value of carotenoid content when compared to meat-based dishes, but a lower chlorophyll content due to the decrease in green color. Regarding saponins, the presence of saponins was evident in the lentil-based dishes (the height of the foam column was less than 0.2 cm) and absent in the meat-based dishes.

Implement Strategies: Teach and Raise Awareness Sensory Analysis

Preferences in attributes A1 (Appearance), A6 (Digestive process), A7 (Price) and A8 (Nutritional contribution), showed significant statistical differences ($p<0.05$) when comparing the scores obtained for each of the dishes (Table 8). With respect to appearance (A1), the ceviche based on lentils or meat was preferred over the Bolognese dish (meat or lentils). But there was a greater preference for both dishes which were prepared with lentils.

It is possible to observe, in relation to attribute A6, lentil-based dishes were rated higher for both ceviche and bolognese when compared to meat-based dishes. Similarly, with respect to price (A7) and nutritional contribution (A8), lentil-based foods were rated better than meat-based foods. The highest preferences for lentil were due to its price and nutritional value. Participants

Table 8: Comparison of response variables (attributes) of 4 food dishes.

	Saucers					Statistical results		
Response variable	1	2	3	4	C.V.	Significance	Media	LSD
A1	$7.10^{ab} \pm 1.287$	$7.70^{a} \pm 0.823$	$7.70^{a} \pm 0.823$	$6.8^{ab} \pm 1.398$	19.469	0.0416*	6.875	1.228
A2	$6.40^{b} \pm 1.430$	$8.00^{a} \pm 0.943$	$6.20^{b} \pm 0.789$	$6.8^{ab} \pm 1.814$	19.965	0.2426ns	6.85	1.254
A3	$7.70^{a} \pm 1.059$	$7.70^{a} \pm 1.059$	$6.20^{b} \pm 0.919$	$6.60^{ab} \pm 1.955$	18.168	0.0981ns	7.05	1.175
A4	$5.90^{b} \pm 1.595$	$8.0^{a} \pm 0.816$	$5.7^{b} \pm 1.494$	$6.9^{ab} \pm 1.595$	22.831	0.1545ns	6.62	1.388
A5	$7.2^{ab} \pm 1.317$	$7.8^{a} \pm 0.919$	$6.3^{b} \pm 1.636$	$6.6^{b} \pm 1.430$	17.982	0.0756ns	6.97	1.150
A6	$5.9^{ab} \pm 1.663$	$7.1^{a} \pm 1.524$	$4.7^{b} \pm 1.160$	$6.9^{a} \pm 1.729$	21.949	0.005**	6.15	1.238
A7	$4.9^{b} \pm 1.729$	$8.5^{a} \pm 0.527$	$4.9^{b} \pm 1.729$	$8.0^{a} \pm 1.414$	20.336	<0.0001**	6.57	1.227
A8	$5.5^{b} \pm 1.269$	$8.4^{a} \pm 0.669$	$5.5^{b} \pm 1.841$	$8.4^{a} \pm 0.669$	14.886	<0.0001**	6.95	0.949

Means ± standard deviation with different letter in a column are statistically different ($p<0.05$). LSD (Least Significant Difference) (LSD, $\alpha=0.05$), C.V.: Coefficient of variation. Significance: ns; indicate that there is no significance; *: indicates that there is significance; **: When there is high significance. Appearance (A1), Chewiness (A2), Flavor (A3), Odor (A4), Taste (A5), Digestive process (A6), Price (A7) and Nutritional contribution (A8).

are aware of the nutritional value of lentils and sprouts and their low price. Learning other options for dishes and controlling the amount of saponins can be a strategy to opt for more frequent consumption. The participants do not have the same awareness of the possible environmental benefits of consuming lentils and reducing meat consumption.

Evaluation of the Increased Frequency of Lentil Consumption

Figure 5.5 shows the evaluations obtained from the 10 subjects investigated regarding why they would make changes in their lentil consumption, after having received the transfer of knowledge and sensitization. The dimensions evaluated were P1: Sensory preference, P2: Importance because it could improve digestive processes, P3: Price, P4: Health benefits due to its nutraceutical power, P5: Environmental impact, P6: Savings in protein cooking costs due to the gas used and P7: Reduction of environmental impact-reduction of gases in the atmosphere. The maximum score for the importance of the change to be adopted and the reason for it is 5. The question indicated with question P4 has the highest score (4.8), followed by P3 and P5 (4.7). This means that the participants will make the changes mainly because of the possible benefits to their health for its nutraceutical power, for price and for reducing the environmental impact, being their highest priority of people to decide about their changes.

Periodic Follow-up

The last step of the educational intervention model is the periodic follow-up. This point focuses on people who obtained a positive result in the evaluation of changes in awareness, generating interest in adjusting their habits to incorporate lentil-based dishes as a sustainable option. The follow-up is offered from a close accompaniment to give advice and guidance, as well as feedback according to individual needs that arise along the way. The discussion was about the importance of forming follow-up groups to encourage and teach each other. In an exercise of mutual learning, as is marked by transdisciplinarity.

Economic Aspects of Food Dishes

Table 9 shows the cost of Mexican pesos for each ingredient involved in the formulation of the four dishes. Dishes T0 and T0* are those prepared with beef (shredded and ground). The costs of these dishes amounted to $230,145 and $240,145, respectively. In the case of T1 and T2 dishes made with lentils, the cost is $40.39 and $22.39 pesos. The costs are calculated for

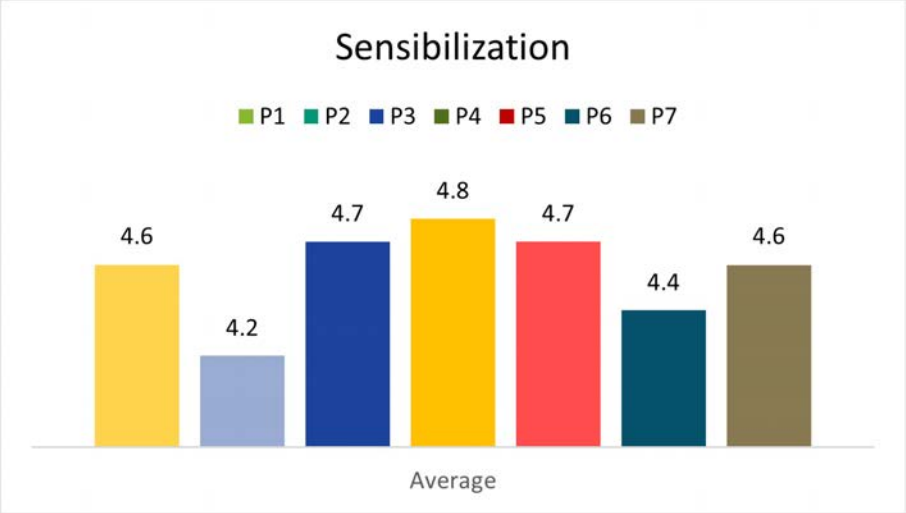

Figure 5.5: *Importance of factors leading to changes in lentil consumption frequency (Scale 1-5) (P1: sensory preference, P2: importance because it could improve digestive processes, P3: price, P4: health benefits due to its nutraceutical power, P5: environmental impact, P6: gas savings, and P7: reduction of environmental impact-reduction of gases into the atmosphere) .*

a yield of 4 to 6 servings. In a population with low minimum wages, with the need to choose nutritious foods with a lower glycemic index, as well as to have sustainable development, the option of lentil consumption would be appropriate due to its beneficial social, economic, and environmental impacts.

Table 9: Costs in Mexican pesos of 2 lentil-based and 2 beef-based dishes.

Dishes	Cost in Mexican pesos ($).									
	Image of the dishes	Lentils	Salt	Pepper	White onion	Tomatoes	Garlic	Chopped mango	Ground beef	Shredded beef.
T0		0	0.75	0.64	9	10	0	20	0	190
T1		9	0.75	0.64	9	10	0	20	0	0
T0*		0	0.75	0.64	9	10	2	0	200	0
T2		9	0.75	0.64	9	10	2	0	0	0

T0: Shredded beef ceviche; T1: Lentil ceviche; T0*: Ground beef bolognese; T2: Lentil bolognese.

Sustainable development is one of the imperatives worldwide, one of the foods of the future that have been established among others, is legumes (FAO, 2018) [53]. Lentils not only could be foods of the future but of the present. They are also one of the crops that have a tolerance to various stress conditions (Balboa, 2020) [54].

According to estimates, in the near future (a few years) more than 50% of the world's adult population will be overweight or obese (Sánchez-García et al., 2014) [55]. For this reason, strategies have been sought to help reduce this percentage and improve health.

One of the strategies is to bring about changes in the population by implementing educational interventions. In general, these cover a set of motivational, pedagogical, methodological, and evaluation actions, whose objective is that the participants reach the points established in the program and make changes in some dimension of their lives (Jordan et al., 2011) [56]

In the present investigation, the purpose of knowing different lentil seeds is to select those

with the best nutritional attributes and with an accessible cost for the preparation of dishes. Of the 15 varieties analyzed, it was found that they have differences in relation to the amount of protein, carbohydrates, and cost. In this way, the model used proposes a characterization stage in the process of knowing to choose. In addition, there are bioactive elements in lentils such as saponins. Saponins are glycosidic substances considered as anti-nutrients and are found in the seed shell (Bonilla et al., 2019) [57]. Saponin is the cause of some gastrointestinal problems, such as bloating, diarrhea, and flatulence in some people who consume legumes (Carolina et al., 2014) [58]. Because of the possible discomfort caused in some consumers, alternatives are sought to reduce them. In the present intervention, people were also taught how they could reduce it, through the heating of the lentil, through UV-C radiation, or through the germination process, etc.

In the model used for the intervention, the follow-up stage of the participants is distinguished. Some authors have reported significant results from the follow-up of people in educational interventions (Pimentel et al., 2014) [59]. Follow-ups focused on motivation and accompaniment, as well as providing constant and adequate information according to the doubts that arise help people to generate security and better results (García and Suárez, 2003) [60]. Follow-up in a purposeful environment that allows participants to feel confident in the steps they will take to prevent or treat a health situation according to the required needs gives a better result than just carrying out the educational intervention without any follow-up (Trento et al., 2004) [61]. In fact, there is the opportunity to generate changes over time and not just momentary ones.

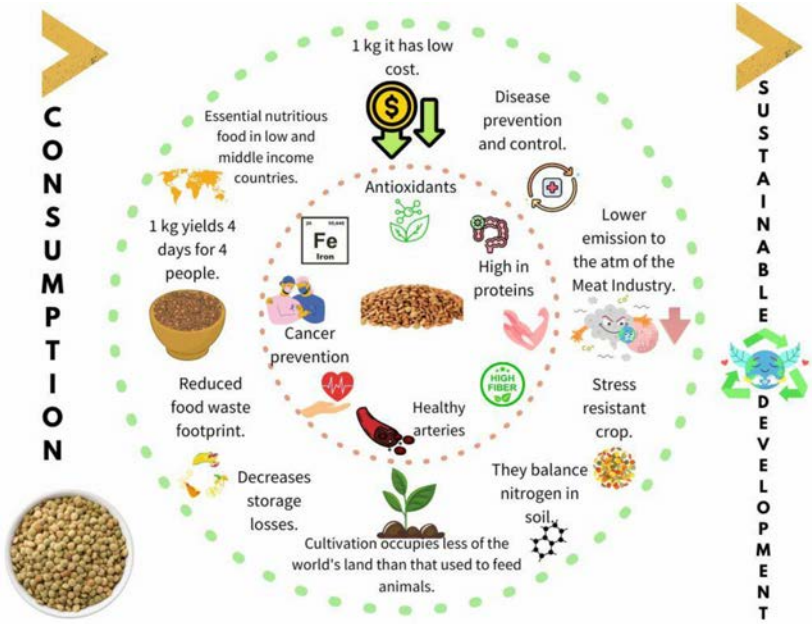

Figure 5.6: *Lentil consumption, a strategy for sustainable development.*

In this educational intervention, it was found that the main changes people would make would be due to the low cost of lentil-based dishes, health benefits, and environmental protection. In this way, these decisions could have an impact on sustainable development, as shown in Figure 5.6, impacting due to the invested cost, in the face of populations that cannot afford to invest in meat-based dishes. Opting for lentil consumption leads to a chain of favorable impacts. It would have an impact on a decrease in meat consumption, a decrease in energy used to cook food (meat

takes longer to cook than lentils). The amount of land used to produce foliage for livestock feed would be reduced. In this way, gas emissions into the atmosphere could be reduced. In this chain of impacts, the environment could be improved. Finally, and very relevant is the improvement in the nutritional health of the population.

Thus, an educational intervention model is proposed to increase the consumption of this legume.

5.4 Conclusions

Almost all the people (71% of whom had an age range between 20 and 40 years and 73.6% had a bachelor's degree) surveyed in the population evaluated were from families with diabetes and arterial hypertension. Of the people surveyed, more than 50% were overweight or obese, no one knew the glycemic index of foods, all consumed a diet with high carbohydrate foods such as bread rolls, sweet bread, fruit, rice, and tortillas, and no one had a culture of periodically self-monitoring their blood glucose, nor did the participating diabetes patients. Knowledge and interest in health issues was scarce. They consumed the meat and knew little about the sustainable benefits of lentil consumption, nor were they accustomed to sprouting lentils for consumption. They also had low consumption of lentils before the intervention. Only 18.86% of the respondents agreed to participate in the educational intervention, forming a focus group with them.

The proposed intervention model could be useful in other populations, since it allowed changes in decisions and preferences in the focus group, people could increase their consumption by becoming aware of the importance of lentil consumption for sustainable development, and could modify their preferences and frequency of consumption by learning about the diversity of lentil-based dishes, have possibilities to choose the most appropriate lentil characteristic and also learn to eliminate saponins from lentils so that they do not produce inflammation.

In the process of lentil characterization, it can be concluded that all varieties have affordable costs with different capacities to germinate, differences in carbohydrates and amount of saponin. The study of lentils allowed to choose the most convenient to be consumed by people and not to impact discomfort (intestinal inflammation) by its consumption.

The 10 people who participated in the sensory analysis indicated liking and surprise for the dishes presented, highlighting their interest in increasing the frequency of lentil consumption. The food dish (T1), named lentil ceviche, was the most accepted. All participants indicated that they wanted the recipe booklet as well as the infographic that was previously explained. People who are interested in knowing their health status mostly look for alternatives to modify their eating habits and economy, since lentil consumption is cheaper than beef, and lentil sprouts increase their nutraceutical properties.

In the intervention strategy, the follow-up of the participants was a relevant element in the intervention. The changes of the participants were mainly due to the cost of lentils, environmental awareness, and their own health benefits.

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EJMO) reviewed and critically edited the text and results, and finally approved the manuscript.

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About the Authors

Yoliztli Cecilia Torres Tenorio is a sixth semester student of the Doctorate program in Systems Engineering within the Engineering Systems research line at the National Polytechnic Institute (IPN) of Mexico. She is a chemical engineer by profession with a master of science degree in systems engineering. She has worked in engineering and project areas in the southern industrial zone of Mexico. Her goal is to bring benefits to society through research.

Claudia Hernandez-Aguilar is a professor and researcher of the National Polytechnic Institute, within the Graduate Program in Systems Engineering of ESIME Zacatenco. She is the leader of the Research Group on Sustainable Biophysical Systems for Agriculture, Food and Medicine. She is a member of the Mexican Academy of Sciences and the National System of Researchers (Mexico). Since 2012, she has been a member of the Editorial Committee for the International Agrophysics journal. She has published her research in international journals and

has received over 500 citations. Her focus is the use of engineering e.g., sustainable biophysical methods and photothermal techniques to improve society's quality of life and wellbeing. In times of pandemic, she has proposed educational interventions for the consumption of nutraceutical and low glycemic index foods, as well as the care of the other, the other and the others. She has trained young transdisciplinary researchers for the past 15 years, emphasizing the need for awareness, conscience, rigor, and humanism in the research process and of a Transdisciplinary systemic view on the impact obtained from it. Motto: Transform yourself, to transform your world.

Efraín José Martínez Ortiz. Academic Background. Bachelor's Degree in Education and Bachelor's Degree in Mathematics (Universidad Nacional Mayor de San Marcos Lima Peru), Master's Degree in Mathematics (CINVESTAV Mexico). Specialization in Operations Research, Grenoble France. Teaching Experience. Universidad Nacional Mayor de San Marcos. Lima Peru 1968-1970; Universidad Nacional Autónoma de México 1975-1996, Instituto Politécnico Nacional 1973 to date. Instructor in the formation of human resources in Special Projects of SEP and in different universities of the Mexican Republic Academic and/or Administrative Function.

CHAPTER 6

Transdisciplinary Interventions to Improve the Sustainability of Maize Agroecosystems: A Case Study from Mexico Fertilizer

Martha E. Domínguez-Hernández, Elisa Domínguez-Hernández, Guillermina Martínez-Barrera, Arnulfo Domínguez-Hernández, Rosalba Zepeda-Bautista

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The municipality of Ahuazotepec presented a complex food insecurity scenario, mainly because there are limitations regarding food supply/local maize production and the inhabitants so their access to food can be disrupted quite easily. A transdisciplinary approach and methodology were adapted to analyze, design, implement, and evaluate an agricultural intervention to improve agroecosystems in the region using agroecological practices. The experimental results indicated that the application of agroecological fertilization management improved soil fertility indicators, grain yield, benefit-to-cost ratio, and the resilience of the system. For the intervention, when a transdisciplinary scheme in which collaboration between actors was intensified, the benefits are greater than in a conventional scheme, where only economic or in-kind aid is provided, even when based on similar practices.

Keywords: Sustainability, agroecosystems, transdiscipline, agroecology, food security.

6.1 Introduction

Agriculture encompasses all the activities through which human beings manage and transform natural resources to produce food and other goods. According to Gliessman [1], agriculture is a process that takes place in three dimensions: environmental or biophysical, economic, or techno-economic, and social or socio-political. This means agricultural systems are complex and dynamic, due to the interactions that occur between these dimensions, their elements, as well as the associated natural and human systems [2, 3].

Despite this complexity, most agricultural research and interventions tend to be structured and separated by disciplines and are oriented to specific outcomes of the system, such as yield or resistance to adverse factors. Achieving agricultural growth has been indeed important, given its role in increasing per capita income and reducing poverty and hunger in developing countries, leading to the economic transformation observed in the 20^{th} century, particularly during the Green Revolution [4]. However, this conventional agricultural intensification approach also

caused adverse effects such as the contamination of water bodies, reduction of soil fertility, and loss of biodiversity [5, 6]. These unintended but serious consequences reflect the limitations of the hyper-specialization in which agricultural research and science have submerged, the lack of interaction and cooperation between scientific disciplines, as well as a prevalence of reductionist and non-systemic visions during the design of agricultural interventions [7–9].

In this context, Francis et al. [10] mentioned that, although disciplinary approaches and interventions are helpful in increasing production, they are inherently incompatible with the sustainability of the agroecosystem. In this case, sustainability means that both economic and social/human developments are promoted in a fair and environmentally compatible way [11]. For agriculture, ensuring that agroecosystems are sustainable means they have stable yields, are socially acceptable, are resilient to the effects of external factors, and prioritize the use of agricultural practices that preserve the natural resources used for production and have a low environmental impact [12, 13]. Thus, humanity needs to abandon the paradigm of "increasing yield at all costs" since increasing productivity is only the first step in improving the agroecosystem as a whole [4]. Additionally, it is worth remembering that achieving the Sustainable Development Goals requires combining the three dimensions of sustainable development: *economic, social, and environmental* to solve the most pressing problems of humanity, both in rich and poor countries. Sustainable agriculture is directly or indirectly linked to the goals centered on attaining food security, reducing hunger, improving nutrition, protecting the environment, reducing inequality, and promoting lasting, inclusive, and sustainable economic growth.

It is also necessary that in the present and the future, improvements and impact assessments in agricultural systems are approached from a holistic, systemic, inter, multi, and transdisciplinary perspective, to avoid negative trade-offs when an agroecosystem improvement is proposed. Agricultural research under a Transdisciplinary perspective can also overcome the disconnection between academia and social problems, integrating researchers with problem actors, in order to generate holistic knowledge that corresponds to reality and that solves problems of a complex nature [9, 14, 15]. The participation and knowledge of the actors are key to obtaining valid local diagnoses, defining specific research priorities, and helping in joint impact evaluations. Indeed, the FAO et al. [4] establish that such local and regional diagnoses are needed to assess the role of agriculture, direct the required interventions, guide the required interventions and sequence the measures that will be applied.

Considering all of the above, this article presents a case study where a Transdisciplinary perspective [15] was applied to improve the sustainability of the maize agroecosystem in a Mexican municipality via the design, implementation, and evaluation of a comprehensive agricultural management plan.

6.2 Methodology

6.2.1 Study Site Description

The research area is located in the municipality of Ahuazotepec (20° 00'06"- 20° 07'06" N and 98° 03'42"- 98° 10'24" W) in the state of Puebla, consisting of 21 communities as shown in Figure 6.1 [16]. The municipality is located in a high-altitude valley characterized by plateaus and mounts with varying elevations between 2000 and 2600 m above sea level. Soil is predominantly medium textured andosols, suitable for agriculture and livestock production. Ahuazotepec has two major rivers, the Totoloapa and the Tlachinalco, as well as intermittent creeks that join those mentioned and several springs used for drinking and agricultural irrigation. The climate is temperate and humid, with a rainy season in summer and a frosty-dry season in winter, with mean annual temperatures of 13.2 °C and 804 mm of total rainfall [17].

According to the most recent censuses, the population is 11,439 inhabitants (48.8% men, 51.2% women), with a median age of 25 years or less and an average household size of 4.1 people.

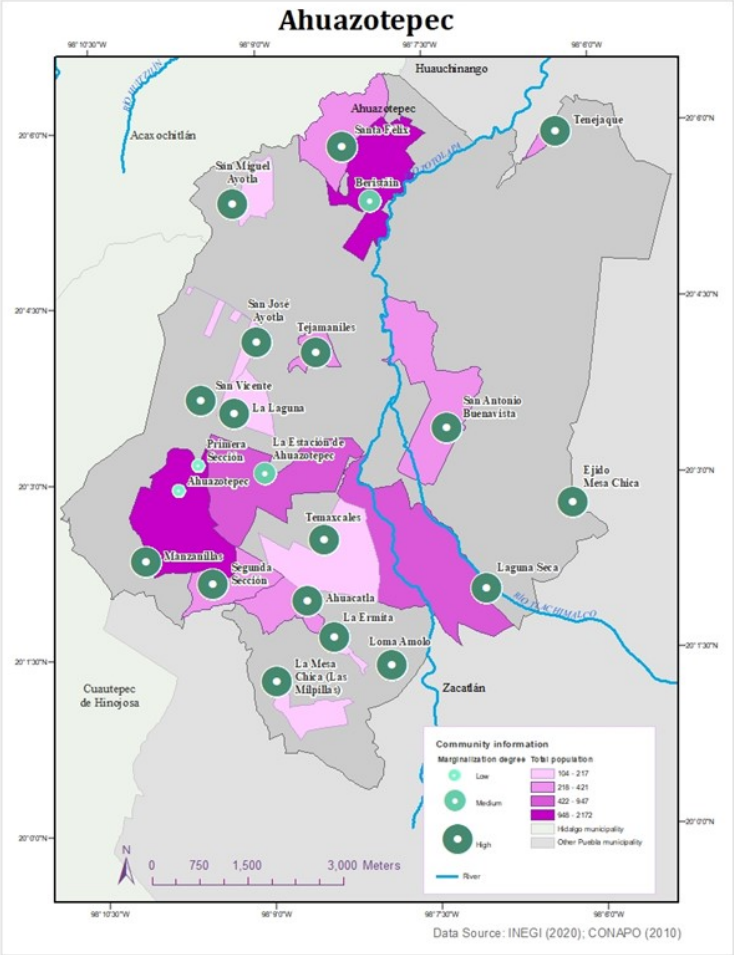

Figure 6.1: *Ahuazotepec municipality: Marginalization degree and population. Data taken from [18, 19].*

Over half of the inhabitants live in the communities of Ahuazotepec, Beristáin and Laguna Seca [16, 19, 20] (Figure 6.1). Nearly 44% of the population is considered economically active 70% is engaged in agricultural activities [21].

6.2.2 Transdisciplinary Approaches to Real-World Problem Solving

There is a current trend toward reducing synthetic inputs in agricultural production, that is, making it more friendly to the environment and health [12]. However, these approaches must also consider the additional pressure of increasing productivity in regions with high yield gaps for staple crops such as maize [22, 23]. Thus, to close yield gaps, it is necessary to intensify agricultural production in a sustainable manner, rescuing and optimizing traditional agroecological practices.

This project was developed by applying the Transdisciplinary meta-methodology proposed by

Hernandez-Aguilar [15] which consists of four stages or phases: (1) Research contextualization: to establish the baseline situation of the system, define the real-world problem and obtain evidence of it, and select response variables to monitor. (2) Solution proposal and experimental evaluation: to produce socially robust knowledge and ensure the solution is acceptable and feasible for the community; implies incorporating society and academia and integrating/adapting one or more scientific methodologies. (3) Implementation of the solution and impact assessment: actors are further integrated to assess the effects of the solutions and provide feedback for collaborative improvement. These phases exist within a framework of self-research and reflection (Phase 4) aimed to promote collaborative work and further interaction with the studied system and the actors [15, 24, 25].

The methodological framework was implemented as follows:

- Phase 1 and 4: The characterization of the municipality of Ahuazotepec, Puebla as a study system, was carried out by establishing its physical, temporal, productive, institutional, and socioeconomic limits and borders considering the existing information [26]. For the initial characterization, statistical data available through institutional sources on agricultural production in the municipality were collected. Additional information that was not available in institutional or academic databases was obtained using various participatory tools, such as surveys, focus groups, interviews, as well as consulting/interviews with local authorities and cooperating producers. Likewise, and in order to comply with the self-investigation framework, ethnographic research tools were used, mainly observation, dialogue, and reflection, in order to understand the behaviors and practices of the system under study and establish links based on empathy and identification with the actors that are part of it [27]. In this stage of the investigation, a modification of the Framework for the Evaluation of Management Systems incorporating Sustainability Indicators (Spanish acronym: MESMIS) was used. This framework is designed to be applied to agricultural, forestry and livestock systems, under collective or individual management [28]. This methodology was used to carry out a diagnosis of municipal sustainability which is detailed in Dominguez-Hernandez et al. (2018) [29]. This diagnosis made it possible to define critical points with which the scope of action was delimited, so that the most pressing specific problems are addressed and to establish the bases for the possible solution to be proposed and the measures that were taken in the interventions.

- Phases 2 and 3: During these phases, the experimental evaluation of the solutions and their effects on the previously defined response variables defined is required. In general terms, the intervention incorporates agroecological principles and practices to improve the production of maize grain. It was designed with an approach that involved collaborative work with the actors of the system including producers, academics, and the local government. Agricultural experiments were carried out at the plot level, to experimentally validate agroecological practices [30, 31] that would address the productivity limitations (critical points) of local agroecosystems. Finally, a management plan (intervention/solution) based on the results, was designed, proposed, and evaluated at a pilot scale to know its impact on the lives of local producers.

The following section presents in detail the results of the creation process, such as the results of the experimental evaluation of the solution, and its subsequent implementation at a pilot level in the municipality.

6.3 Results and Discussion

6.3.1 System Characterization: Maize Production

In the state of Puebla, as in the rest of the country, maize is the predominant crop and agroecosystem, since more than 80% of the cultivated area is dedicated to it.

It is considered essential for the food security of small producers since between 19.9 and 52.4% of grain production (960 thousand 406 t) is used for self-consumption [32]. This corresponds with the percentage of family subsistence units that make up 73% of the total rural production units in the country, which are mainly concentrated in the states of Mexico, Guerrero, Chiapas, Oaxaca, and Veracruz [32].

Accordingly, in Ahuazotepec the bulk of grain production is destined for self-consumption. And, as it is common in the municipalities of the Sierra Norte of Puebla, most maize grain is nixtamalized to produce tortillas. In Ahuazotepec, the agroecosystem is composed of a mixture of smaller systems, mostly characterized by low input use, low technology, and low yields. These conditions reflect those prevailing in the Sierra Norte de Puebla and in the country since maize is cultivated in agroecosystems that combine modern and traditional practices. According to data from the National Agricultural Survey [33] about rainfed production units: the majority use native or landrace seeds (61.7%), employ some type of fertilizer (24.3% organic, 67.4% chemical) and other agrochemicals (59% herbicides, 45.7% insecticides), but often lack access to mechanization for agricultural labors such as planting (29.2%) or harvesting (15.4%).

Although mean maize production is above the national annual per capita consumption (196.4 kg), in the years between 2010-2016 there was also a decrease in maize yield, despite the subsidies available to increase food productivity (PROGAN/PROAGRO, PROCAMPO). These state federal subsidization programs have been available since the 1990s but have clearly failed to increase maize yield in Ahuazotepec. This is because they are often applied late and do not contain training or agricultural extension components that help use resources more efficiently [29, 34].

Taking all this information into account, Ahuazotepec seems to present a complex scenario. There are limitations regarding local agricultural production, and agriculture-derived income, and, despite government efforts, the prevalence of poverty is high. This situation means that low-income households that depend on maize production, even if they are not classified as food insecure, may risk insufficient intake of nutrient-dense foods, making them vulnerable to suffering from malnutrition [35].

Addressing the Critical Points that Affect the Productivity of the Maize Agroecosystem in Ahuazotepec

According to the MESMIS analysis, two critical points were determined in this agroecosystem: chemical fertilization and weed control, which also correspond to 32 and 42% of production costs, respectively. But also have negative environmental impacts such as pollution due to lack of knowledge and training for their correct use. Additionally, producers lack opportunities to sell their landrace grains in more lucrative markets and often stop their cultivation in favor of more profitable but also more expensive varieties. The local diagnosis also brought more light to the effects of low productivity on the food security of farming families. On the one hand, the percentage of the producer's income derived from maize is less than 10%, which means they depend largely on non-farm income and on food-aid programs to supplement household income. On the other hand, low maize production reduces their food self-sufficiency, since 50% of farmers obtain yields below the municipal average and therefore cannot cover the basic needs of their families [29].

Even though the limitations described are big, it is possible to ensure the productivity of agroecosystems via the optimization of certain local production practices. Previously we iden-

tified [29] traditional producers with yields of 4 t per hectare, in systems where agroecological practices are used; these included the application of manure, the use of native seeds and adequate manual or mechanical weed control. These practices are based on traditional knowledge, and although the yield may be arguably moderate, they tend to be more stable due to low dependence on external inputs and the high agrodiversity within the production units [1, 12].

Regarding the use of agricultural inputs based on organic sources, the research group evaluated biofertilizers made with residues from livestock production and nixtamalization. Results of these experimental trials indicated organic sources produced average maize yields 2.1 tons higher than those obtained using chemical fertilization [30]. Additionally, in another experiment, the use of manure-based soil amendments and mulches was shown to lower the incidence of weeds in agroecological systems. This meant reduced the need for weeding and thus the agricultural workload while maintaining the benefit of collecting edible weeds/forage free of agrotoxic residues [31]. In addition, the recovery of nutrients contained in manure and other organic wastes allows mitigating the polluting potential of agriculture [36]. Also, the use of manure and wastewaters increased energy efficiency by 27% more than chemical fertilization [30]. In economic terms, organic fertilization generated a benefit-cost ratio up to 88% higher than conventional fertilization. Finally, to the benefits mentioned, these agricultural experiments reported that the agroecosystems where this type of fertilization or amendments are used become more resilient to adverse climatic phenomena.

Design, Evaluation, and Implementation of the Intervention

Considering the problems described in the previous sections, and based on the needs of the community, it was necessary to define, implement and evaluate a comprehensive management plan aimed at the sustainable improvement of the maize agroecosystem, and that would also increase the food security of participating producers. The results of experimental and pilot-level evaluations carried out to validate the application of agroecological practices in this agroecosystem are presented below.

Collaborative Experiment to Evaluate Agroecological Practices in the Yield of Creole Maize and Soil Properties

In data from a survey applied to 95 maize producers in the municipality of Ahuazotepec, Puebla, differences in the yield and incidence of pests and weeds were identified, particularly in units where agroecological practices are carried out (e.g., manure application). To establish whether the differences in these variables were caused by changes in the soil due to agroecological management, the research group established a controlled experiment in the production unit of a collaborating farmer scientist.

Design and Establishment of the Experiment: An experiment was established in the spring-summer cycle of 2017, in the "Rancho Laguna Seca" production unit. Three treatments were evaluated: Control (no fertilizer application), Sheep manure (25 t ha^{-1}) and Chemical (115 N-00 P-00 K, source: urea). The response variables or indicators were maize yield and soil properties. Each treatment was replicated three times; the experimental unit consisted of six furrows ten meters long and 0.8 m wide, considering the two central furrows as the useful plot. The preparation of the land consisted of mechanical ploughing and furrowing, followed by sowing. A landrace variety of dark blue or black Elotes cónicos maize obtained from producers in the area was planted. The planting date was May 12, 2017, and a planting density of 62,500 plants per ha was used.

Soil sampling was done before planting (April 20, 2017) and after harvest (November 10, 2017). The samples were taken at a depth of 30 cm, they were obtained from the central part of each experimental unit; they were dried in the shade, ground, and sieved with a 2 mm mesh.

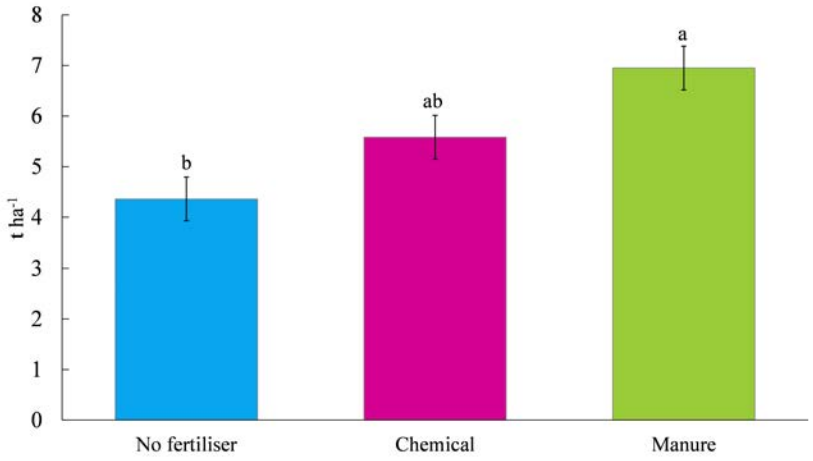

Figure 6.2: *Grain yield (t ha^{-1}) in Creole maize grown in Ahuazotepec, Puebla, PV-2017 cycle.*

Nitrogen, phosphorus, and potassium were determined by reading with the c215 Grow meter. Master Basic (Hanna Instruments®), the percentage of organic matter with the Walkley and Black method, in addition, for each sample the apparent density was determined with the test tube method [37]. The performance was determined in t ha-1, considering a 12% moisture content, was calculated as: GY = (FW x% DM x% G)/8800 [38], where FW = cob field weight in kg; %DM = dry matter percentage; %G = percentage of grain.

Evaluated Indicators: Yield and Soil Properties: Grain yield presented significant differences between the evaluated treatments (P = 0.04). The plots where manure was applied had an average yield of 6.9 t ha^{-1}, where chemical fertilizer was applied 1.37 t ha^{-1} less were obtained and in the plots, without application, the average yield was 4.36 t ha^{-1} (Figure 6.2).

The results of the experiment are in accordance with those reported by Miron et al. [39], who obtained increases of 25% in maize yield in treatments with manure application compared to inorganic fertilization. Mucheru-Muna et al. [40] reported that the application of 6 t of bovine manure per hectare increased yield by 15% in soils with good fertility and 67% in poor soils compared to inorganic fertilization. Opala et al. [41] found that 6 t ha -1 of manure provided 60 kg ha^{-1} of nitrogen, increasing maize yield by 5% compared to treatments where the same amount of nitrogen was provided with urea. These results correspond to local reports where it was found that producers that use manure reported yields above 4 t ha^{-1}, while conventional management with chemical fertilizers decreases the maximum yield to 3.5 t ha^{-1} [29]. Additionally, weed problems were reported in 39. % of the units where manure was applied, while only 16% reported pest damage; both values were lower than those reported in producers that carry out conventional management (27.5% reported pests and 39.6% weeds).

Organic matter content decreased in the control and chemical treatments by 0.8 and 0.4%, respectively. The treatment with manure had an increase of 0.05% during the cycle, results that agree with those reported by Meng et al. [42] and Wang et al. [43], as well as the trends reported by Salazar-Sosa et al. [44] and Trejo-Escareño et al. [45]. The differences found were not statistically significant (P = 0.869), however, the experimental units that have been managed conventionally and with the application of chemical fertilizers had the lowest organic matter content of the group (Figure 6.3a).

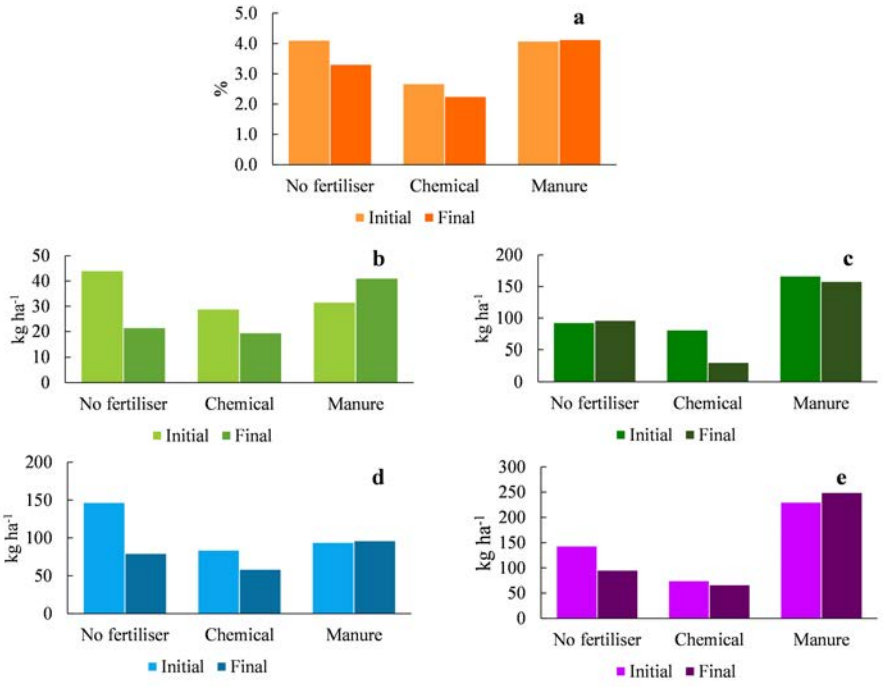

Figure 6.3: *Soil properties evaluated in creole maize cultivated in Ahuazotepec, Puebla, PV-2017 cycle. a: Organic matter content (%), b: Ammoniacal nitrogen (kg ha^{-1}), c: Nitric nitrogen (kg ha^{-1}), d: Available Phosphorus (kg ha^{-1}), e: Potassium (kg ha^{-1}).*

Ammoniacal nitrogen (NH_4^+ -N) increased 31% in the treatments with 25 t of sheep manure per hectare; the chemical fertilization units had a reduction of 9.4 kg ha^{-1}, while those where no fertilization was applied had a decrease of 22.6 kg ha^{-1} (Figure 6.3b). The differences were not statistically significant (P = 0.155).

The nitric nitrogen (NO_3^--N), reported in kg ha-1, decreased by 37.7% in the treatments with chemical fertilization and 5% in plots where manure was applied, the differences were statistically significant between the control and the chemical treatment (P =0.027), where the first had a (NO_3^--N) 3.6 units higher than the latter (Figure 6.3c).

A similar trend was found by Dinesh et al. [46] who obtained increases of between 45 and 48% using organic management with 66.6 t ha-1 of manure combined with neem, ash, vermicompost/microorganisms, and by Wang et al. [43] who report increases between 22.9 and 24.7% after three years of application of 52.5 t ha^{-1} bovine manure. Salazar-Sosa et al. [44] reported average increases of 330% with respect to treatments without fertilization. This was explained by the fact that Nitrogen content tends to increase when organic matter content is high since microbial activity favors its mineralization [43, 46].

The amount of phosphorus (PO_4^{-3}) decreased 30% in the units with chemical fertilizer application and 45.8% in the control; while manure treatments had an average increase of 2.2%, the differences found were not statistically significant (P = 0.584) (Figure 6.3d). This behavior coincides with that reported by [42].

Potassium content increased 8.4% in manure fertilization treatments, while control and chemical fertilizer units had a decrease of 33.5 and 10.1%, respectively (Figure 6.1e), the differences

were not statistically significant (P=0.77). The first results coincide with those found by Salazar-Sosa et al. [47], who reported increases of up to 30.4 ppm in applications of 160 t ha^{-1} of manure with respect to the control treatment.

Taken together, the results indicated that agroecological practices improved soil quality. One of the main benefits of the use of organic fertilizers is the conservation or improvement of soil quality through the provision of organic matter, which in turn is related to greater stability and resilience in food production systems based on agroecological principles [12].

Intervention 2: Government Program to Increase the Economic Sustainability of the Maize Agroecosystem

In the municipality of Ahuazotepec, Puebla, according to data from a survey applied in 2015 [29], it was determined that the average yield of maize for grain of producers of the traditional self-consumption agroecosystem is 1.55 t ha^{-1} with a benefit-to-cost ratio of 22 cents for each peso invested, however, 50.9% of these producers did not cover the per capita consumption. Considering the critical points, it was determined possible to increase the economic sustainability of the system through the integration of agroecological practices and the modification of the conventional production process, to make more efficient use of resources for production.

Solution Design and Implementation: The intervention was co-created with the participation of academics from the research group, producers and the local Department of Agriculture, Commerce, and Industry. The initiative was presented to the Municipal Council, giving rise to the "Program to increase the economic sustainability of the maize agroecosystem in Ahuazotepec, Puebla". The program was implemented in the spring-summer production cycle of 2017. The objective of the program was to increase the economic sustainability of the maize agroecosystem in Ahuazotepec, Puebla through the establishment of experimental production units managed under a proposed technological package.

The selected production units were 26 (14 under irrigation conditions and 12 under rainfed conditions) and belong to maize producers in food vulnerability. Within the program, two approaches were used: the first where institutional participants and the producer worked in collaboration to carry out the activities inherent to the production process and apply the agricultural inputs provided (TS, Transdisciplinary Scheme, Figure 6.4), and the second, a scheme where agricultural inputs and technical advice are provided upon the producer request, but no further collaboration was expected (CS, Conventional Scheme, Figure 6.5).

The practices proposed and promoted included fertilization using manure (previously validated), split fertilization, mulching and soil amendments, application of mechanical cultivation to reduce the incidence of weeds, reduction in the use of agrochemicals, the application of emergency irrigation and the use of higher planting densities, among others [30, 48, 49]. In the CS, the producers were shown how to apply the practices and what they entailed during a series of visits to the "Rancho Laguna Seca" experimental unit. However, they made the final decision as to if and which proposed practices they would use in their plots. Decision making in the TS was done collaboratively, with trained collaborators and producers discussing the alternatives and coming up with the best practice to be used.

Definition of Indicators: The selected indicators were yield and cost-benefit ratio. Grain yield (GY) was determined in t ha^{-1}, considering a 12% moisture content, was calculated as: GY = (FW x %DM x % G)/8800 [38], where FW = cob field weight in kg; %DM = dry matter percentage; %G = percentage of grain. Benefit-to-cost ratio (BCR) on the experimental plot was calculated as in Dominguez-Hernandez, et al. [29] using the average production costs per hectare ($6,300) and the value of the grain obtained in each cycle, considering a sale price of 4,900 MXN per t valid in Ahuazotepec during 2017.

Figure 6.4: *Production of maize in Ahuazotepec Puebla under the "Program to increase the economic sustainability of the maize agroecosystem in Ahuazotepec, Puebla". Transdisciplinary Scheme.*

Figure 6.5: *Production of maize in Ahuazotepec Puebla under the "Program to increase the economic sustainability of the maize agroecosystem in Ahuazotepec, Puebla". Conventional Scheme.*

Evaluated Indicators: Yield and Benefit to Cost Ratio: The program generated an improvement in the economic dimension of the maize agroecosystem for all the beneficiaries.

Yield increases of between 50 and 3,500 kg per hectare were reported, with an average value of 1,323 kg ha^{-1}. The average yield was 2.7 t ha-1 with an average cost-benefit ratio of 2.12, that is, 1.12 pesos for each peso invested. Up to 73% of the beneficiaries had positive values in the BCR, which indicates that with the proposed management program they were able to increase the yield and recover the initial investment. Despite reporting increases in GY, at least 15% of the beneficiaries obtained yields of less than 1.2 t ha^{-1}, which even though lower than the average, is the amount necessary to cover the grain needs of a family unit for one year.

Considering the results of the program, and the two schemes of implementation, it was found that the Transdisciplinary Scheme increased an average of 1465.8 kg per hectare, while the increase in the group under the Conventional Scheme was 538.4 kg. This result may indicate that the design of programs where different actors of the system participate constantly during the production cycle generates greater benefits than those obtained with conventional schemes where only economic or in-kind assistance is granted.

When the program was designed, it was observed that there is a resistance to change rooted in the producers. This could be explained due to their previous experiences with government interventions in which they were left alone and there was no training or technical assistance to guarantee the results and the implementation of the proposed changes, which were often difficult to perform. Because of this, it was considered pertinent that the proposed modifications were small and relatively simple to carry out, in order to be accepted and subsequently replicated by the farmers after visiting the experimental unit. Also, the producers were continuously reassured there would be technical assistance available in case they needed it.

A high number of the producers who participated in the interventions expressed interest in making and sustaining the proposed changes to their systems, mainly because they observed increases in yield and lower production costs. However, the adoption and interest levels for both schemes were different. After the intervention, 100% of the participants in the TS adopted at least one of the proposed modifications, mainly manure fertilizers, higher planting density, split fertilization, and rational or reduced use of machinery and agrochemicals for cultivation, mulching, and soil amendments. In contrast, the CS only achieved 50% of long-term adoption of the improved practices once the government financial support was finished. This finding is similar to those of other intervention studies, where the integration of the community via a transdisciplinary approach, was key to ensuring adoption and continuity of the proposed solution as well as feedback on its performance, constant improvement and mutual learning [18, 50].

It has also been found that the success of agricultural interventions is also linked to the inclusion of education and training elements in their design (see Domínguez Hernández et al. in this special issue for a review [49]). More importantly, the collaboration element may have helped the beneficiaries to prevent disadoption of the proposed practices by providing continuous support, emotional and technical, needed to overcome possible limitations, strengthen community integration, and increase ownership of the program [51, 52]. In the present case, we attribute the higher rate of sustainable practice adoption to the collaboration and mutual learning aspects during the TS; since producers were able to learn the practices but also to freely adapt them and combine them with their own personal agricultural knowledge to address the specific biophysical conditions of their This could be explained due to their previous experiences with government interventions in which they were left alone and there was no training or technical assistance to guarantee the results and the implementation of the proposed changes, which were often difficult to perform. Because of this, it was considered pertinent that the proposed modifications were small and relatively simple, in order to be accepted and subsequently replicated. The producers who participated in the intervention expressed interest in making changes to their systems and to date have maintained the proposed changes, especially in fertilization practices. This finding is similar to those of other intervention studies, where the integration of the community via a transdisciplinary approach, was key to ensuring adoption and continuity of the proposed solution as well as feedback on its performance, constant improvement and mutual learning [15, 50].

Follow-up visits were planned in 2020 to check if the changes were maintained by the community, however, due to the COVID-19 pandemic they were postponed until the spring-summer of 2021. During this visit, some of the beneficiaries stated that currently their production units are in transition toward complete agroecological management, and some have even fully adopted it. This was attributed to problems related to accessing agricultural inputs, particularly chemical fertilizers, first due to reduced availability and then increases in the cost, both of which have worsened in the last few years due to the pandemic and conflicts such as the Russo-Ukrainian war. Another aspect that could have contributed to this deeper agroecological change is the experience and knowledge sharing that could have occurred between participants from the TS and those from the CS one who had not yet adopted many agroecological measures. According to Altieri et al. [12], the ability to withstand external shocks such as this is a testament to the increased resilience of agroecology adopters. Additionally, the continuous and wider application of sustainable practices that reduce agrochemical use also reduces the possibility of future environmental problems that may compromise the health and livelihoods of the intervention beneficiaries [53].

6.4 Conclusions

The design of interventions for the improvement of agroecosystems requires a multidimensional, systemic, and transdisciplinary approach that not only makes possible the implementation of the proposals in real-world conditions but also improves the possibilities of success. As observed, interventions with a transdisciplinary approach had a greater impact on the community than those developed under the conventional scheme commonly used in support of Mexican agriculture. Additionally, it was observed that focusing on agricultural indicators of a multidimensional character such as measures for energy use efficiency, soil fertility, weed/pest incidence, and even some ecosystem services was required to address the challenges of local maize production. We hope that monitoring these indicators in the long term will help maintain natural resources and sustainability. Finally, cooperation between all actors was key to ensuring the success of the program and to helping in developing and implementing the solution. Government, academics, and producers can learn from each other in all stages, but in the latter case, we observed that participant involvement during the intervention was intensified, going from information providers, to consulting and finally to empowerment and ownership of the solution.

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Author contributions: MEDH had the idea for the research, adapted the methodology and conceived the experiments along with EDH. MEDH, ADH, EDH and GMB performed the experimental, laboratory and intervention parts of the project, and analyzed the results. EDH and MEDH drafted the manuscript and prepared the visual elements. MEDH, EDH, and RZB, all secured funding for the research. All authors critically revised and edited the text and results, and finally approved the manuscript.

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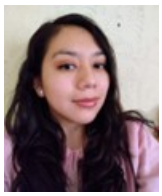
About the Authors

Martha Elena Domínguez-Hernández is a Professor and researcher in the Department of Agronomic Sciences of the National Autonomous University of Mexico, as well as a member of the National System of Researchers. She is interested in the agricultural application of multidimensional sustainability impact assessment, participatory research, systems thinking and geographic information systems. Using these tools, her research focuses on the understanding of Mexican Agroecosystems and sustainable intensification of production to meet the food needs of a growing population while reducing environmental impact.

Elisa Domínguez-Hernández is a Postdoctoral Researcher at the Autonomous University of Queretaro and is a member of the National System of Researchers. Holds a PhD in Systems Engineering from the National Polytechnic Institute (ESIME-Zacatenco) and a double M.Sc. in Animal Science and Food Science from the Swedish University of Agricultural Sciences and the University of Helsinki. Her research relates to Sustainable Food and Nutrition Security, understanding, and studying, the different elements of the food production system (farm to table), and their impacts on the supporting human and natural resource systems. ORCID: 0000-0002-7879-1944



Guillermina Martínez-Barrera is an undergraduate student in Agricultural Engineering at the Cuautitlan Faculty of Higher Studies of the National Autonomous University of Mexico (UNAM). She has actively participated in research and teaching projects related to the monitoring and assessment of sustainability in agroecosystems. ORCID: 0000-0002-2738-7044

Arnulfo Dominguez-Hernández has a Bachelor in Mechanical Engineering by the UNAM. Currently on track for obtaining his master's degree at the Systems Engineering Graduate Program of the National Polytechnic Institute of Mexico (IPN). He is doing Transdisciplinary research on agriculture-livestock integrated production systems and has participated as a government liaison during the development and implementation of interventions aimed to improve agroecosystems holistically. ORCID: 0000-0001-9409-2329

Rosalba Zepeda-Bautista is a Professor-Researcher at the Systems Engineering Graduate Program of IPN. Doctor in Genetics and Seed Production. Belongs to the National Researchers System. Her research interests are related to sustainable food production systems, food processing and quality, seed technology and quality, genetic improvement of plants, as well as biological and physical methods for sustainable production. She has published her research on national and international journals and conferences. ORCID: 0000-0003-0988-8619

CHAPTER 7

Effect of Stationary Magnetic Fields on Medicinal Plants

Mª Victoria Carbonell, Mercedes Flórez, Elvira Martínez, Elena Montoya

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In recent decades, physical techniques based on the application of magnetic fields (MF) have been developed in the agricultural sector with favorable results in plant germination and growth. The main objective of this study is to determine the effects of magnetic treatment on the germination Salvia officinalis L. and Calendula officinalis L. seeds. Groups of seeds were exposed to MF of 125 mT for different times, other groups of seeds were subjected to magnetic pretreatment and others were used as control. Germination tests were performed under laboratory conditions. The parameters were: germination time of the first seed (T1), time for reaching 10 -75% of germination (T10, T25, T50 and T75), mean germination time (MGT) and number of germinated seeds (Gmax), provided by Seedcalculator software. The parameters recorded for both species with treatment and pretreatment were lower than the value of the corresponding control, chronic exposure at 125 mT provided the highest results; MGT was significantly reduced compared to controls. (T1-T50) were also significantly reduced.

Keywords: Magnetic treatment, seed germination, Bioelectromagnetism, *Salvia officinalis* L., *Calendula officinalis*

7.1 Introduction

In Mediterranean countries there is a great development of medicinal, spice and aromatic plant crops due to their high added value as a consequence, among other reasons, of the reappearance of Phytotherapy. Recently, magnetic seed treatment has become very popular in the agricultural sector, the number of articles in Bioelectromagnetism focusing on the investigation of the magneto-sensitivity of living organisms has increased in the last decades. Seed germination and plant growth has become an attractive model for studying the biological effects of magnetic fields, in addition to the geomagnetic field [1]. This objective has a practical application in agricultural science: to obtain early growth of medical plants. Studies with rice and onion showed that magnetic pretreatment improved germination and vigor of seedlings from low viability seeds [2]. According to these studies, pretreatment with magnetic field had a positive effect on cucumber seedlings, stimulating the growth and development of the seedlings and their roots [3]. Higher germination percentage and germination rate of cereal seeds exposed to magnetic fields have been obtained; higher contents of albumin, gluten and starch were obtained in wheat seeds exposed to magnetic field [4,5]. A possible mechanism associated with magnetism has been proposed to accelerate tomato maturation [6]. “Calendula” and “salvia” are used as a condiment in food,

but they also have some medicinal properties due to their essence content. They are cultivated for the food, herbal, cosmetic and liquor industries [7].

In previous studies, the authors found that magnetic treatment at 125 mT and 250 mT produced bio stimulation in the early growth stages and increased germination rate of rice, wheat and barley seeds [8-11]. The researchers studied the effect of corn seed germination and concluded that the time required for germination recorded for each magnetic treatment was less than the control values, so the germination rate of treated seeds was higher than that of untreated seeds. Growth data measured 7 and 10 days after sowing corroborated the effect observed in the germination tests. Significant differences were obtained between the length and weight of corn seedlings subjected to a magnetic field of 125 mT and 250 mT for different times versus the control [12]. A positive response has been observed in grasses; exposure to the magnetic field provides earlier germination, increases the number of germinated seeds, reduces germination velocity, and increases stem and root length of Festuca arundinacea Schreb. and seeds of Lolium perenne L. [13]. In addition, exposure to 125 mT and 250 mT MF has been studied in pea and lentil seeds [14], growth parameters (total and stem weight, total and stem length) measured on days 7 and 14 increased, and increased root development was observed.

The main objective of this study is to evaluate the effect of magnetic treatment on the germination of seeds of *Salvia officinalis* L. and *Calendula officinalis* L., by exposing seeds to a stationary magnetic field of 125 mT for different periods of time and pre-germinative exposure. This objective has a practical application in agricultural science: to obtain early growth of medicinal plants.

7.2 Material and Methods

Germination tests were performed to study the effect of seed exposure to a stationary magnetic field of 125 mT. The test was carried out under laboratory conditions with natural light and average temperature of 20 ± 2°C for *Salvia officinalis* L. and 25 ± 2°C for *Calendula officinalis* L. Seeds of uniform size and shape without visible defects and malformations were selected. Groups of salvia seeds were exposed to magnetic field varying the exposure time (A1-A5) and another group of seeds was subjected to magnetic pretreatment (P1) for 24 hours prior to sowing. The CM was generated by 125 mT magnets. The geometrical characteristics of the cylindrical magnet are external diameter of 7.5 cm, internal diameter of 3 cm and height of 1 cm. Analogous rings, made of the same material, but without magnetic induction, were used as control. Exposure times were: 10 min (A1), 20 min (A2), 1 h (A3), 24 h (A4) or chronic exposure (A5). An experimental design with four replicates (n=4) was carried out, with 25 seeds in each. Thus, groups of 100 seeds were subjected to each magnetic treatment and analogous groups were used as controls. Groups of *Calendula officinalis* L. seeds were exposed to 125 mT for 24 h (A4) or chronic exposure (A5) and compared with the control (C1), another group of seeds was subjected to magnetic pretreatment (P1) for 24 h. Prior to sowing and compared with the control (C2).

Germination tests were performed according to the guidelines issued by the International Seeds Testing Association [15] with some minor modifications. The seeds from each replicate were placed in Petri dishes on filter papers soaked with 12 ml of distilled water. The seeds were placed around a circular line; thus, all seeds were subjected to the same magnetic field intensity, and the Petri dish was placed onto the magnet. For dose A5, Petri dishes were placed over the magnets for the entire experimental time. For the other doses, the Petri dishes were placed on the magnets for the corresponding time 10 min, 20 min, 1 h and 24 h (A1-A4) or magnetic pretreatment before seeding (P1). Subsequently, they were placed on a ring without magnetic induction. The control group of Petri dishes was placed in blind rings (without magnetic induction) from the beginning of the experiment.

The number of germinated seeds for each treatment was recorded three times a day during the test period. Seeds were considered germinated when their radicle was at least 2 mm long.

The germination parameters evaluated were elapsed time to germination of the first seed (T1), germination time of 10, 25, 50 and 75 % (T10, T25, T50 and T75), number of germinated seeds (Gmax), and mean germination time (MGT) and correlation coefficient (R2), all provided by the Seedcalculator software package developed for seed germination data analysis by Plant Research International.

7.2.1 Statistical Analysis

Germination data obtained for the magnetic treatments were compared using the t-Student value and significant differences between each treatment and the control were calculated using Seedcalculator software. Statistical analysis of growth data was performed using SPSS 11.0 software for Windows. Results were subjected to analysis of variance (ANOVA) to detect differences between mean parameters. Means were compared using Tukey´s test (multiple comparisons) and Dunnet´s test to detect significant differences between parameters of treated and control plants.

7.3 Results and Discussion

Salvia officinalis

The germination parameters obtained for *salvia* seeds are shown in Table 1. The results show that the germination percentage (G_{max}) was higher for the magnetically treated seeds. Parameters T1 and T10 were significantly reduced for all magnetic treatments, implying that the onset of germination occurred before. The T1 value of seeds not exposed to magnetic field was 72.96 h while this value for A4, A5 and P1 were 23.04, 22.56 and 25.20 h, respectively. Significant reductions were also obtained for the parameter T25. The mean germination time (MGT) of salvia seeds was significantly reduced when the seeds were exposed to FM. The highest differences between treated and control seeds were obtained when seeds were treated for 24 h and chronically exposed (81.84 h for A4, 75.60 h for A5 vs. 95.28 h for the control). In addition, the other parameters evaluated, MGT, T_{50} and T_{75}, were also reduced. Consequently, the percentage and germination rate of salvia seeds exposed to a stationary magnetic field of 125 mT were increased.

Table 1: Salvia germination parameters

Dose	R^2	G_{max}(%)	Time (hour) $\bar{x} \pm SEM$					
			T_1	T_{10}	T_{25}	T_{50}	T_{75}	MGT
C	0.98	47±4.4	72.9±0.7	78.9±0.7	83±0.7	88.8±8	97.4±1.9	95.3±2.1
A1	0.96	60±4.3	34.1±4.3^b	57.4±4.3^a	73±3.2	91±4.3	110±5.5^a	92±2.2
A2	0.96	63±4.4^b	27.3±1.4^d	48.2±2.4^d	62.6±2.9^d	79.7±3.3^b	97.7±4.1	80.6±3.3^b
A3	0.94	56±4.3	25.4±3.4^b	46.8±1.1^b	61.7±5.9^b	79±4.1^a	98±1.2	79.7±3.6^b
A4	0.97	69±1.9^b	23±2.9^d	44.2±2.6^d	59.8±2.1^d	79.2±2.4^b	101±4.5	81.8±2.9^c
A5	0.98	58±5	22.6±5.2^d	41.3±2.8^d	55±2.4^d	72.5±4.3^b	92.6±5.5	75.6±2.6^c
P1	0.94	65±5^a	25.2±5.1^b	47±3.3^b	62.4±6.1^b	80.6±4.5	99.8±2.2	81.6±5.8^a

Figures 7.1a, b and c show the cumulative germination curves of *Salvia officinalis* L. for the applied magnetics treatments and control. In the graphs, it can be observed that, in all cases, the germination curve of the control is below the curves of the treated seeds, which implies that the germination rate of the control is lower than that corresponding to all the magnetic doses. The germination percentage of the control seeds is always below that corresponding to all magnetic treatments.

Germination parameters of *Salvia officinalis* L. seeds exposed to 125 mT, expressed as mean (±) standard error. Exposure times: 10 min (A1), 20 min (A2), 1 h (A3), 24 h (A4), chronic

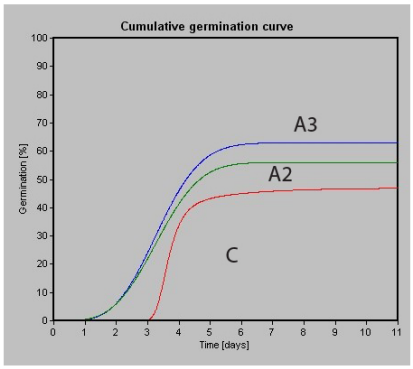

Figure 1a. Germination curves of *Salvia officinalis* L. seeds exposed to 125 mT for 20 minutes (A2), 1 hour (A3) and control (C).

A3
A2
C

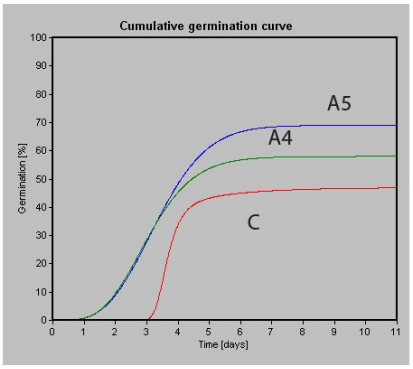

Figure 1b. Germination curves of *Salvia officinalis* L. seeds exposed to 125 mT for 24 h (A4), chronic exposure (A5) and control (C).

A5
A4
C

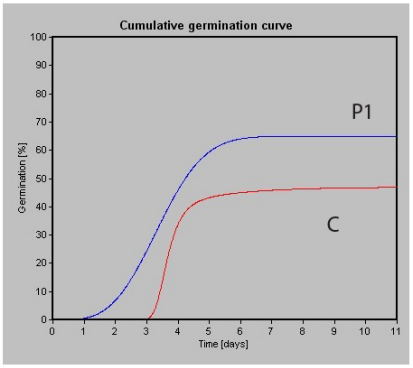

Figure 1c. Germination curves of *Salvia officinalis* L. seeds exposed to magnetic pretreatment with 125 mT (P1) and control (C).

P1
C

Figure 7.1: *Cumulative germination curves of Salvia officinalis L. seeds.*

exposure (A5), pretreatment (P1) and control (C). G_{max}: number of germinated seeds (%); MGT: Mean Germination Time; T_1, T_{10}, T_{25}, T_{50}, T_{75}: time required to obtain 1, 10, 25, 50 and 75% of germinated seeds expressed in hours. R2: Correlation coefficient. Superscripts indicate differences vs. control: ^{d}($p<0.001$): extremely significant; ^{c}($0.001<p<0.01$) very significant; ^{b}($0.01<p<0.05$); significant; ^{a}($0.05<p<0.1$): differences.

Table 2: Calendula germination parameters

Dose	R^2	G_{max}(%)	Time (hour) $\bar{x} \pm SEM$					
			T_1	T_{10}	T_{25}	T_{50}	T_{75}	MGT
C1	0.99	72±4.7	25.2±2.7	36.5±1.7	44.4±0.9	54±0.5	65.3±1	56.2±0.2
A4	0.98	71±4.4	27.4±2.4	37.4±2.9	44.4±3.8	53±3.9	63.4±4.5	55.2±4.1
A5	0.99	80±4.3	28.3±2.2	36.5±1.7	41.8±1.4	48.7±1.2^d	57.4±1.7^d	50.8±1.7^c
C2	0.94	80±4.7	14.9±2.9	21.6±3.1	25.9±1.4	31±0.5	36.2±1.7	31.2±0.7
P1	0.97	84±3.3	10.8±3.8^b	17.3±2.2^b	21.8±0.5^b	27.8±1.4	34.8±3.6	29±1.7

Calendula officinalis L.

The germination parameters calculated for the seeds of Calendula officinalis L. are recorded in Table 2. The results show that the times required to obtain the different germination percentages were reduced. In most cases, for magnetic treatment (A4, A5) vs. control (C1) and all germination parameters were reduced for pretreatment (P1) vs. control (C2). The improved results were obtained for chronic exposure (A5).

Germination parameters of *Calendula officinalis* L. seeds exposed to 125 mT, expressed as mean standard error. Exposure times: 24 h (A4), chronic exposure (A5), pretreatment (P1) and controls (C1 and C2). Gmax: number of germinated seeds (%); MGT: Mean Germination Time; T_1, T_{10}, T_{25}, T_{50}, T_{75}: time required to obtain 1, 10, 25, 50 and 75% of germinated seeds expressed in hours. R2: correlation coefficient. Superscripts indicate differences vs. control: $^d(p<0.001)$: extremely significant; $^c(0.001<p<0.01)$ very significant; $^b(0.01<p<0.05)$; significant; $^a(0.05<p<0.1)$: differences.

Figure 7.2a shows the cumulative germination curves of Calendula officinalis L. seeds exposed to 125 mT for 24 h (A4), chronic exposure (A5) and control (C1). Figure 7.2b shows the cumulative germination curves of pretreated seeds of calendula (P1) and control (C2). The germination rate and percentage of germination of untreated seeds is higher in the magnetically treated seeds.

The results obtained for both medicinal plants are in agreement with other studies on the influence of a stationary magnetic field on seed germination and plant growth, which reveal that the treatment produces an improvement in the percentage and velocity of germination of the exposed seeds. An increase in germination and sprout development was obtained by exposing maize seeds to a 150 mT magnetic field for 10, 15, 20 and 30 min [16]. Similar results were obtained with tobacco seeds [17]. Primary root curvature was observed in radish seedlings in a static magnetic field and the roots responded to the static magnetic field, significantly with the south pole of the magnet [18]. A positive effect of magnetic treatment on germination and emergence of bean cultivars was proved; plant emergence from magnetized seeds was 2 to 3 days earlier compared to the control, yield increased due to more pods per plant [19]. It was observed that the length of young maize plants exposed to a magnetic field between 50 to 250 mT was greater than the control for all exposed samples [20].

A significant increase in germination, seedling vigor and shoot/root growth of one-month-old plants of chickpea seeds exposed to static magnetic fields has also been published. Cicer arietinum L. seeds were exposed in lots to static CM from 0 to 250 mT in steps of 50 mT for 1-4 h in steps of 1h. The results showed that the magnetic treatment improved the germination performance compared to the control. The combinations of field intensity and exposure time: 50 mT for 2 h, 100 mT for 1 h and 150 mT for 2 h exposure gave the best results [21]. Improvement in seedling growth and root characteristics was also observed in 1-month-old maize plants [22]. Recently, other research conducted with triticale shows that the application of CM of 125 mT or 250 mT favors and advances germination, and plants of greater length and weight are obtained, the most significant differences were obtained for exposure times greater than 1 h [23, 24].

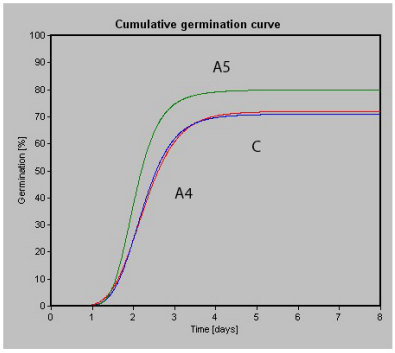

Figure 2a. Cumulative germination curves of seeds of *Calendula officinalis* L. with CM of 125 mT for 24 hours (A4), chronic exposure (A5) and control (C).

A4
A5
C

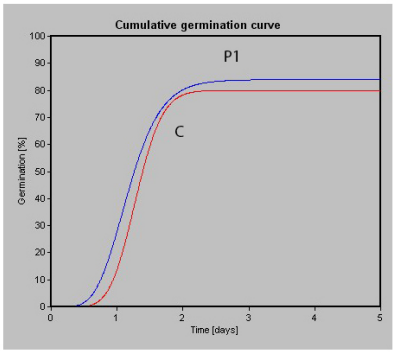

Figure 2b. Cumulative germination curves of seeds of *Calendula officinalis* L. with CM pretreatment of 125 mT (P1) and control (C).

P1
C

Figure 7.2: *Cumulative germination curves of seeds.*

7.4 Conclusion

The results obtained for "Salvia" and "Calendula" seeds show that the germination parameters (MGT, T_1-T_{75}) were reduced for the treatment and magnetic pretreatment compared to the controls. The best results were obtained for 24-hour exposure and chronic exposure. The results indicate that the application of magnetic fields improved the germination rate and germination percentage of treated seeds compared to unexposed seeds in both cases. Consequently, the stationary magnetic field could be used as a physical technique to improve the germination of *Salvia officinalis* L. and *Calendula officinalis* L. seeds.

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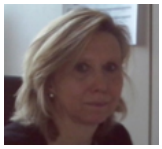
About the Authors

Dra. Mª Victoria Carbonell Padrino, Dra. Agronomist Engineer, Professor of the Dept. of Agroforestry Engineering at the Polytechnic University of Madrid, Spain. She teaches Physics in the Biotechnology Degree. Researcher of the Bioelectromagnetism Applied to Agroforestry Engineering Group, which aims to incorporate new physical techniques, based on magnetic treatment, to agricultural production and conservation of natural resources.



Dra. Elvira Martínez Ramírez, Dra. in Chemical Sciences from the Polytechnic University of Madrid. Teaching. Professor of the Dept. of Agroforestry Engineering, Unit of Physics Applied to Agroforestry Engineering and teaches Physics in the Degree of Biotechnology. She is a member of the Bioelectromagnetism Applied to Agroforestry Engineering Group, conducting research on the application of stationary magnetic fields and their influence on seed germination and plant growth

Dra. Mercedes Flórez García, Dra. Agronomist Engineer. Associate Professor in the Dept. of Agroforestry Engineering at the Polytechnic University of Madrid, Spain. She teaches Physics in the Degree of Food Engineering. Researcher of the Bioelectromagnetism Applied to Agroforestry Engineering Group, which aims to incorporate new physical techniques, based on magnetic treatment, to agricultural production. The Group investigates the influence of stationary magnetic fields on seed germination and plant growth.

Dra. Elena Montoya García-Reol, Degree in Biological Sciences and Dra. Agronomist Engineer from the Polytechnic University of Madrid. Director of Technology, Business Development and Big Data at Oracle. Associate Professor at the ETS Agronomy, Food and Biosystems Engineering, she teaches Physics in the Dept. of Agroforestry Engineering.

CHAPTER 8

Sustainable Development Goals index: An analysis (2000-2022)

Claudia Hernández Aguilar, Francisco Suazo López, F. Arturo Domínguez Pacheco

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In this international year of basic sciences for sustainable development and the edition of the special issue of challenges for sustainable development in the journal TJES. It is of interest to review how the sustainable development index has evolved according to the global fulfillment of the development goals (SDGs) in the world (2000-2022). It was found that since the Millennium Development Goals (MDGs) and subsequently the Sustainable Development Goals (SDGs) were proposed, the greatest increase in the index was reported in periods prior to the Covid-19 pandemic. Among the continents, the European continent is positioned with the highest SDGs index values, mainly the countries of Finland, Sweden, and Denmark (≥85 points). The continent with the lowest index is Africa (38-70). The values of the index in the years 2019-2022, present the highest positive correlation when comparing its value between the countries of each continent, i.e. COVID-19 period affected the progress of sustainable development. The current state of the indicator reflects that there are still countries in each continent where mechanisms must be generated to evolve in the fulfillment of the objectives set out in the 2030 agenda and thus increase the global index of sustainable development for the post-COVID-19 era.

Keywords: Sustainability, ???.

8.1 Introduction

Throughout the history of humanity, human beings have longed for a better world: without poverty, hunger, pain, equality, human rights, quality of life, quality of air, security, tolerance, love, understanding, justice, peace. In this sense, there have been several proposals, declarations, charters, programs, creation of various international organizations and conferences in search of these desires. In general, they have established actions to move towards these great human longings. The Declarations of the Rights of man and of the Citizen (legacy of the French Revolution in 1789), "Declaration of Human Rights" (UN, 1948), the creation of the League of Nations (created in the First World War, 1919) and the United Nations Organization (created at the end of the Second World War) [1-2] provide evidence of this.

In addition to the concerns for a better world in peace and the rights of man, as years went by, the concern for the environment was added. Thus, in 1968, the National Conference on Environmental Education was held in New Jersey-USA [3]. Likewise, Sweden's 1967-1968 intervention in the United Nations - the so-called "Swedish initiative" - led to the 1972 United

Nations Conference on the Human Environment, which was the first to express the environment as a central issue of concern at the international level [4,5] Derived from this world conference was created 1) the United Nations Environment Programme (UNEP), and 2) International Environmental Education Program (IEEP), 3) 26 Basic Principles [3,6]. Through these programs, the goals related to peace, economic and social development, defense, and improvement of the environment is added. The principles adopted by the UN (1972) express the conviction that man has the obligation to protect and improve the environment for present and future generations; involving the responsibility of the people and their governments, where progress must prevail, but with discernment [7-9]. It is worth mentioning that this laid the foundations for what years later would be defined as sustainable development in the Brundtland Report (1987). In which it is understood as that sustainable development "is able to meet the needs of the present generation and does not have to compromise future generations" [10-12].

In addition to this reflection on environmental protection, in 1975 an International Seminar on Environmental Education was held in Belgrade to promote the inclusion of the environmental perspective in the educational area, elaborating the Belgrade Charter, which establishes the principles for environmental education [6, 13-14]. This is reflected in the need for nations to be able to grow, but without prejudice to the other and that the consumption of the individual does not occur to the detriment of others. Evidently, a need for a change in thinking that leads to a global ethic, an ethic of individuals and of society; an ethic that recognizes and responds with sensitivity to the complex and continuously evolving relationships between man and nature and with his fellows. The environmental goal is to form a world population aware of and concerned with the environment and associated problems. The objectives of environmental education are established: awareness, knowledge, attitudes, aptitudes, evaluation capacity and participation. Informal Education is considered necessary and permanent for the entire population, through mass media, articles, and dissemination. This type of education would be informal, in addition to the formal education received in educational institutions [3]. At the Rio de Janeiro conference (1992), the Stockholm principles were endorsed, although the role of women in environmental management and sustainable development, and of young people in achieving it and ensuring a better future for all, was also highlighted (Rio Janeiro, 1992) [3, 15,16].

In 2000, the UN established the six-millennium goals and in 2015, adopted the 2030 Agenda, with a set of 17 interlinked global Sustainable Development Goals (SDGs) [17]. This Agenda represents "a plan of action for people, planet and prosperity" and "seeks to strengthen universal peace in larger freedom". At the Stockholm conference (2022) [18], proposes to accelerate agenda 2030, the achievement of the sustainable development goals for a healthy planet, social and economic progress, well-being, and resilience. Thus, it is of interest to know how we are today, with the Sustainable Development Report (SDR) (Sachs et al., 2022) [19], being issued 50 years after 1) the environment was incorporated as a fundamental issue at the international level and 2) the results of the study prepared by a group of 17 researchers from MIT, headed by Donella Meadows (1941-2001), were published. In the document called "the limits of growth", the researchers project the behavior of variables such as population, pollution level, natural resources, total capital investment (industrialization), and food in 100 years [20-22].

Based on the model of the father of system dynamics Jay Forrester (1918-2016), the team´s Meadows project that the increase in population will cause a decrease in food and resources, pointing out the ecological crisis to which the human being was leading the planet with his actions [19,23]. In that preventive alert carried out in the 70's, added to new crises such as the Covid-19 pandemic, much remains to be done in our world.

But how are we doing in terms of sustainability in the continents? In times of COVID-19, there was progress of sustainable development, what happened in this period in relation to the global indicator of this parameter? From the recent comprehensive sustainable development report, we chose only to analyze the index of SDGs by country and by continent. Reflecting for each objective which countries are leading the way in its fulfillment. Thus, the objective of

this document is to analyze the behavior of the index in the five continents and to give us a global overview of how the countries are doing in each of the continents, integrating data from 2000 to 2022. Knowing their status is useful to continue rethinking and planning urgent present and future actions, and to assume the social and economic challenges and challenges that this implies.

8.2 Methodology

This analysis was based on the indicator representing an overall score (%) towards the fulfillment of the 17 SDGs (from the year 2000-2022) published in the Sustainable development report and interactive data from the website [19,24]. The index is expressed from 0-100, where if the overall score percentage is higher, it means that more sustainable development goals have been reached. The indicator analysis was performed for the five continents. The global scores of various countries on these continents (America (27 countries), Europe (43), Asia (38), Africa (40), and Oceania (3)) were used.

8.2.1 Statistical Analysis

Analysis of variance of the indicator between country values by continent for the years (2000, 2005, 2010, 2015, 2015, 2019, 2020, 2021, and 2022) and the least significant mean (LSD) comparison test were applied [25]. Finally, principal component analysis was applied to correlate the behavior of the indicator of the countries for each continent by year studied. SAS (2008), Project R and Fitopac procedures were used for the analysis [26-28].

8.3 Results and Discussion

SDG Index score per continent

Figure 8.1(a) shows the average values per continent of the SDG Index score (years 2000, 2005, 2010, 2015, 2019, 2021 and 2022-2022). It is possible to observe that the continent with the highest average SDG Index value, according to the countries considered, was Europe, and the lowest position was in Africa. The five continents present an evolution over time, finding the highest percentages of improvement for the years 2000, 2005, 2010, 2015 and 2019, i.e. the highest evolution has been achieved until before the Covid-19 pandemic. In the American continent, there was an improvement of 9.2% in the index from 2000 to 2022. Although it is noteworthy that the rate from 2019 to 2022, decreased by 0.3-0.4%. This means that during the pandemic there was a slowdown in relation to the improvement of the SDG index. In the case of the European continent, the improvement of the indicator from the beginning of the millennium (2000) to August (2022) is 8.68%.

During the pandemic, the indicator showed a slight increase (less than 0.5%). Likewise, Asia during the pandemic period tended to increase (0.5%). With respect to the year 2000 - 2022, it presented an increase in the indicator of 10.59%. It should be noted that the continent with the lowest average indicator values is Africa, although its improvement is the highest of the three continents (13.31%) from the beginning of the millennium to the present (2000-2022), with a growth in the pandemic period of 0.34%.

In relation to Oceania, there was the lowest improvement (3.5%) (according to the SDG index of the countries considered in this study). Likewise, in the pandemic period, the improvement was minimal, with 0.15, 0.26, and 0.27% for the years 2020, 2021 and 2022. Figure 1b shows the comparisons between continents. Statistically, significant differences are observed when comparing the mean values of the SDG index of the continents Oceania with Africa and Europe, and the

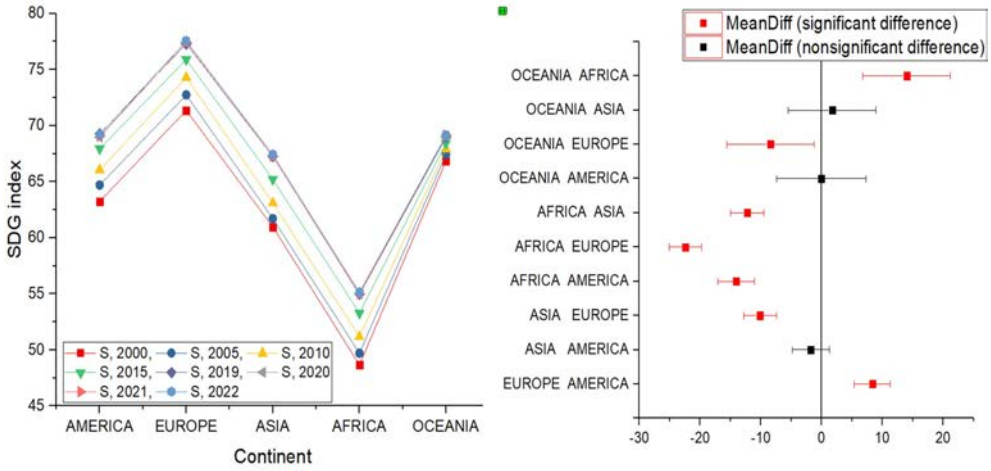

Figure 8.1: *Evolution of sustainable development indicator a) years 2000, 2005, 2010, 2015, 2019, 2020, 2021 and 2022, b) Representation of the minimum significant differences when comparing the behavior of the percentage index between continents.*

comparisons between Africa with Asia, America, and finally when comparing Europe with Asia and America. Statistically, Oceania, Asia, and America have similar behavior, since they did not present significant statistical differences between their average index values for each continent in this period of time (2000-2022).

SDG Index score by country for each continent

The above behavior of each continent is due to the countries that comprise it. Figure 8.2 shows heat maps, which represent the evolution of the SDG index in the years studied (2000-2022) by country in each continent: a) Europe, b) Asia, c) Oceania, d) America, and e) Africa. In the European continent (Figure 8.(2a)), the countries that reached the highest SDG index values are Finland (86.51), Sweden (85.19), and Denmark (85.63). It is worth mentioning that, in the case of Sweden, since the beginning of the millennium, it had the highest SDG index value (83.62) among all European countries and the world. In many countries from the year 2000-2019, there are higher changes of color intensity in the thermal map, associated to the evolution presented in the SDG indicator. It coincides that in the Covid-19 period there was more homogeneity of color in the map of countries. In general, the behavior of the SDG index of the countries is observed, which was with a) slight changes b) no changes and c) others regressed. The highest percentage increase, according to the countries covered in this analysis in the SDG index (from 2000-2022) were Estonia (14.2%) and Uzbekistan (14.9%)

In Asia (Figure 8.(2b)), The countries of Japan and Korea are with the highest SDG index values with respect to the other countries. It is possible to observe that since the beginning of the millennium (2000), both countries had the highest index values. Although Cambodia (30%) and Nepal (26%) are the countries that reached the highest percentage increase when comparing the SDG index in 2000 and 2022.

New Zealand is the Oceania country with the highest SDG index value (78.3) and the highest value since 2000 (76.62). In contrast, Papua New Guinea (PNG) has the lowest SDG index values and Australia has the highest increase (6.22%) when comparing its value in 2000 and 2022 (Figure 8(2c)).

In the Americas (Figure 8.(2d)), the SDG index value ranges from 47.40-77.90, with the most

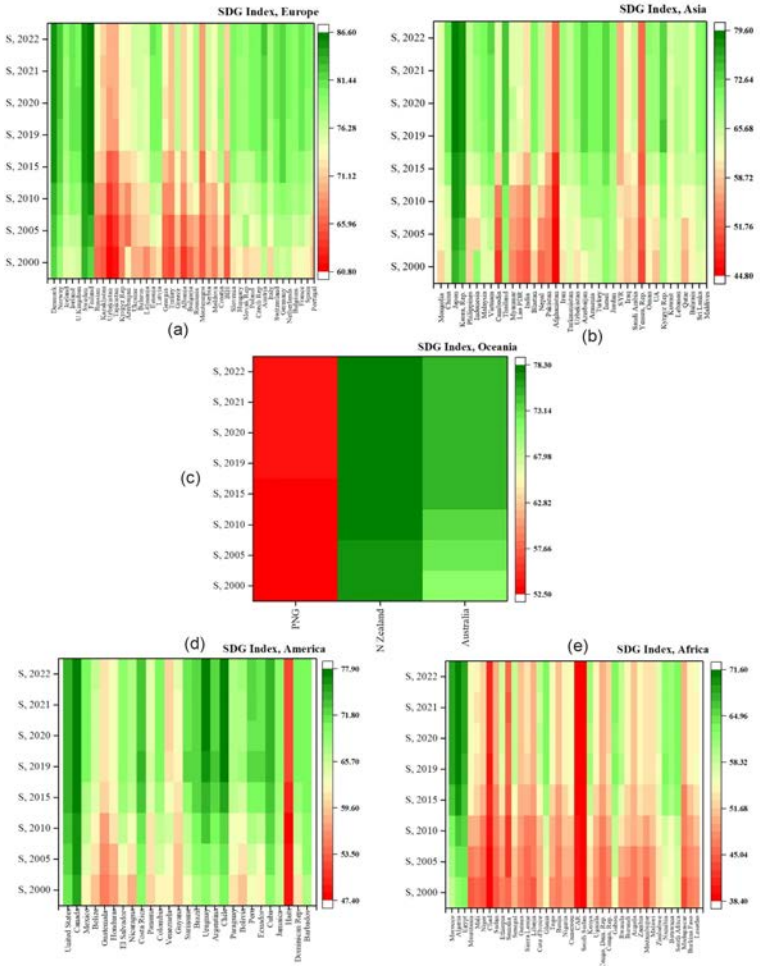

Figure 8.2: *Evolution of sustainable development indicator (2000-2022) by country a) Europe, b) Asia, c) Oceania, d) Americas, and e) Africa.*

stable country with the highest SDG index in 2022 being Canada (77.73); this country since the beginning of the millennium (2000) in this continent was the best rated (74.55).

However, the countries with the higher index increase from 2000 to 2022 are the Dominican Republic (15.1%) and Ecuador (15%). Although at the time of Covid-19 there was no increase, on the contrary, in the case of Ecuador it was rated with a slight decrease in this index during that period (0.3%). It is worth noting that Venezuela decreased its index in 2019 compared to 2015, and in the pandemic period it had another additional decrease.

Concerning the African continent (Figure 8.(2e)), the index in 2022 ranges between the values of 38.40-71.60 and of the countries considered (40), among which more than 50% are rated with an index of less than 55 percentage points. There are countries such as Somalia that have had no movement in their SDG index rating and the Central African Republic (CAR), which even had a slight drop in the percentage of the SDG rated value (0.43). As well as South Sudan with the lowest score obtained in the SDG index since 2000 (38.61) to date in 2022 (39.05),

representing an 80% below the best positioned countries in this continent Algeria (71.54) and Morocco (68.98). Although Rwanda was the country in this continent that presented the highest percentage (24.41%) increase in this index from 2000 to 2022.

It is noteworthy how the pandemic period represented an affectation to sustainable development in the world. This can be seen in the principal component analysis (Figure 8.3). In all Figures 3 (a), (b), (c), (d) and (e), the vectors representing the SDG index values for the years 2019-2022 are more correlated when compared to the years back (2000, 2005, 2010 and 2015). This means that they have a more similar behavior. The Asian continent is the most correlated in the vectors representing this period of years (Figure 3c). On the other hand, in the Americas (Figure 8(3a)) there are 6 clusters (red, orange, yellow, yellow-green, yellow-green, green, and blue) of performance in the SDG index. The countries represented in red (on the right of the graph) are the countries that in this year (2022) have been evaluated with the highest SDG index scores. These include Canada, Chile, and Uruguay, followed by the United States, Costa Rica, Cuba, Brazil, and Argentina. It is possible to observe that Haiti is on the far left of the graph, contrary to those with the highest SDG index (located on the right), since its SDG index rating is the lowest in the American continent (Figure 8(2d)).

On the European continent (Figure 8.(3b)), it is observed that in 2022 five clusters are formed, where it is observed (red symbol) that one of these clusters is formed by the countries with the highest SDG index value (Finland, Sweden, and Denmark). Moving the graph from right to left, the cluster (yellow-green symbol) is formed by the countries of Norway, United Kingdom, Austria, Germany, Holland, Ireland, and France, among others. The countries with the lowest values are located on the left in the clusters with intense and light blue color, among the countries found are Uzbekistan, Tajikistan, Montenegro, Turkey, Albania, Bosnia, and Herzegovina, etc. The angle formed between the vectors representing the years 2000 and 2005 is greater than with respect to 2005 and 2010, 2010 and 2015 and 2015 and 2020. The greater angle is related to a lower correlation, which is associated with higher growth in the SDG index in that five-year period.

For the Asian continent (Figure 8(3c)), the angle formed between 2010 and 2015 is higher than the angle formed between the other five-year periods (2000 and 2005, 2005 and 2010, 2015 and 2020), i.e., the period of highest growth. Unlike what happened in the pandemic period, where the vectors representing the years 2019, 2020, 2021 and 2022 have an angle of almost 0° between them, this means that the behavior was almost the same in the pandemic period.

In Oceania (Figure 8.(3d)) the three countries considered have different behavior, forming three clusters. In the period 2010-2015, it is in this continent where the greatest changes in the SDG index behavior occurred. It is worth noting that the years 2020, 2021 and 2022 are closer to the vector represented by 2010 than 2015. This is associated to the fact that in Covid-19 times, there was a decrease in the evolution of the indicator.

In Africa (Figure 8.(3e)), there was a tendency to increase in the five-year period from 2015-2019, but from 2019-2022, there is a high correlation between the vectors, which could be associated with a similarity in the behavior of the SDG index. The countries with the highest index are classified by clusters (red and yellow symbol) composed by the countries of Algeria, Egypt, Morocco, South Africa, Ghana, Namibia, among others. The countries that have the lowest evaluation in the SDG indicator, form a cluster (deep blue symbol), among which are the countries that are in the lowest evaluation in the SDG indicator (red and yellow symbol). Sudan CAR, Somalia. In these graphs it is easy to visualize the countries that are in the highest growth ranges of the indicator and those that are at the bottom (right and left side of the graphs, respectively).

Finally, Figure 8.(3f)) shows the countries with the best indicators for each continent. The vectors represent indicator behavior in 2019, 2020, 2021 and 2022. It is possible to observe how in the world, the countries with the highest growth are European countries and African countries at the end. The highest growth of these countries is located between 2019 and 2020. Subsequently

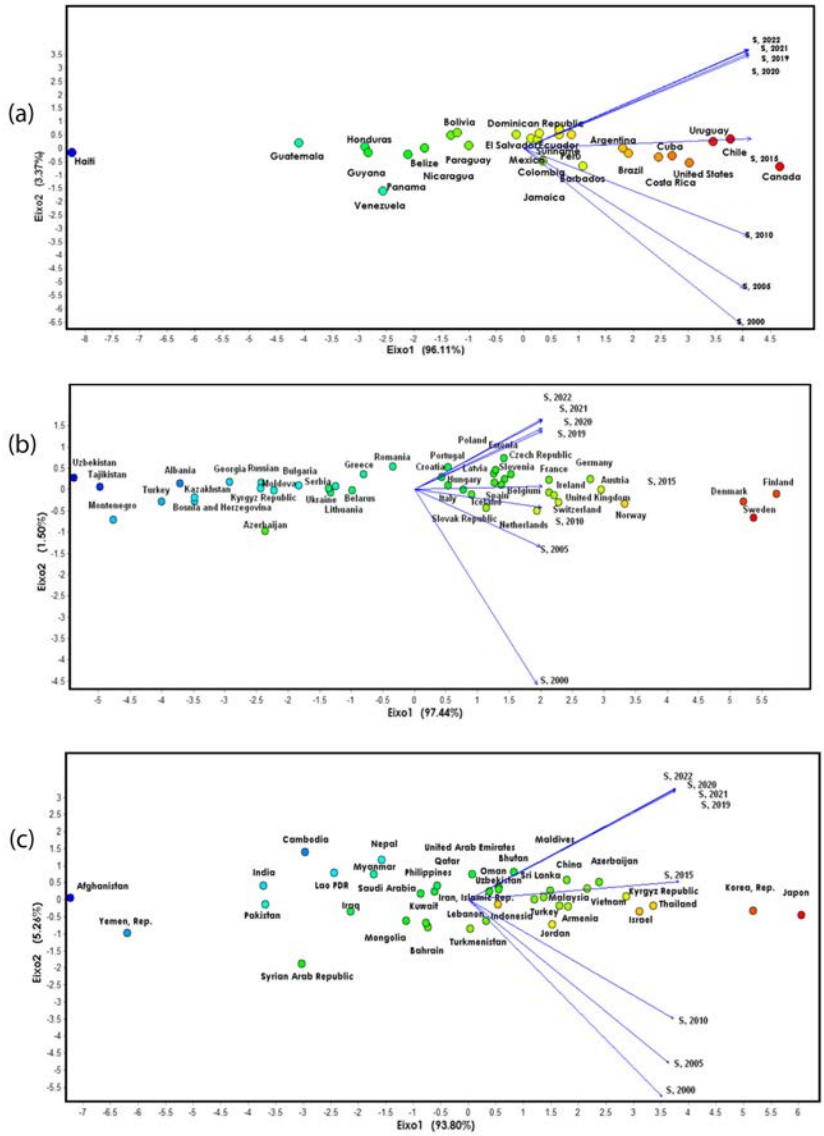

Figure 8.3: *(a)(b)(c): Principal component analysis of SDG index for the years 2000, 2005, 2010, 2015, 2019, 2020, 2021, 2022 in countries of the continents: a) America, b) Europe, c) Asia.*

(2020, 2021 and 2022) the correlation between the vectors increases. Therefore, their behavior is more similar, i.e. there were almost no changes. Thus, confirming the effect on the SDGs index due to the global pandemic.

Figure 8.4 presents the global map of the sustainable development index (2022) in the center [24]. Around the central map are located the 17 global maps that represent the current status of each of the sustainable development goals. It can be seen that the most achieved goals (green

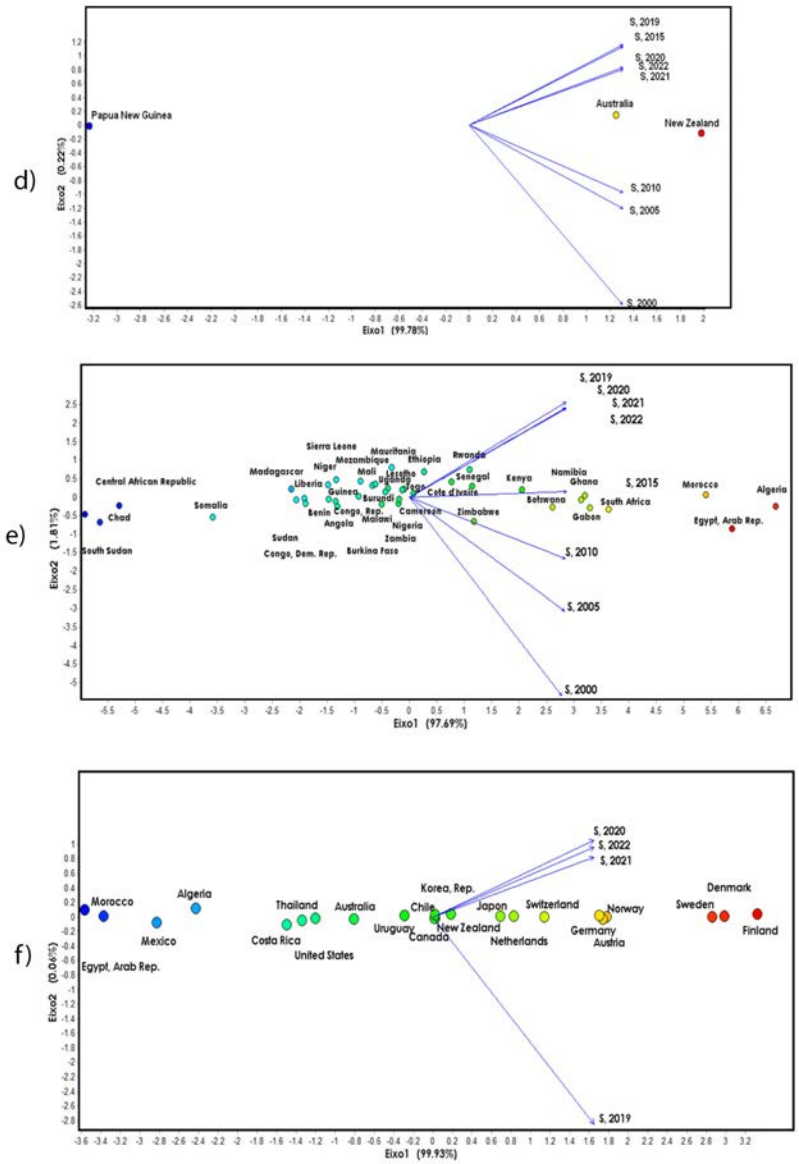

Figure 8.3: *(d)(e)(f): Principal component analysis of the SDG index for the years 2000, 2005, 2010, 2015, 2019, 2020, 2021, 2022 for the countries of the continents: d) Oceania, e) Africa and f) Asia Considering the countries with the highest sustainable development per continent for the years 2019, 2020, 2021 and 2022.*

region) in the world are: 1). No Poverty, 4) Quality Education (ranked in the economic and social dimension, respectively). Other goals achieved in fewer countries were goals 7, 10, 12, and 13 (social and ecological dimension). The goals that are in the most critical situation of non-compliance at the global level are SDGs 2 (economic dimension), 15 (environmental dimension)

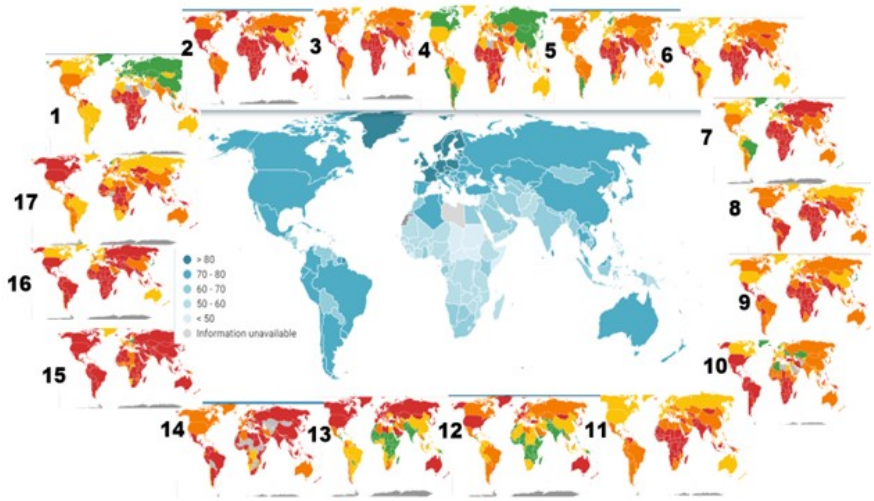

Figure 8.4: *integrates the global maps [24] of each of the sustainable development goals: 1). No Poverty, 2) Zero Hunger, 3) Good Health and Well-being, 4) Quality Education, 5). Gender Equality, 6) Clean Water and Sanitation, 7) Affordable and Clean Energy, 8) Decent Work and Economic Growth, 9) Industry, Innovation, and Infrastructure, 10). Reduced Inequality, 11) Sustainable Cities and Communities, 12). Responsible Consumption and Production, 13). Climate Action, 14). Life Below Water, 15) Life on Land, 16) Peace, Justice, and Strong Institutions, and 17) Partnerships. (Green region: "SDGs achieved", Yellow: "Challenges remain"; Orange: "Significant challenges remain", and cherry: "Significant challenges remain", grey: Information not available).*

and 16 (social dimension). Table 1a, 1b and 1c detail the status of each of the goals in the world that have been classified as a) Best-performing or challenges remain and b) Major Challenges remain and "Significant challenges remain".

It is possible to observe that in the objectives related to the economic dimension (1, 2, 3, 8 and 9) there are objectives where no country in the world has achieved them (2, 3 and 8). It is worth mentioning that objective 9 is only achieved by Japan. In general, the African continent is the one that presents the most critical situation in its fulfillment of objectives (Table 1a). On the other hand, Table 1b shows the status of the objectives that address the social dimension (4, 5, 10, 11, 16 and 17). Only objective 11 has not been met by any country. There are goals that have been achieved by countries in Asia and Europe, Goal 10 (Japan), Goal 16 (Japan and Iceland) and Goal 17 (Norway). The continents that still present major challenges are Africa, America, and Asia to a much greater proportion.

Regarding the fulfillment of objectives in the environmental dimension (6, 7, 12, 13, 14 and 15), the objectives achieved by some countries are 7, 12, 13 and 15. Objectives 6 and 14 have not been met by any country. In this dimension (Table 1c), the fulfillment of objective 12 (responsible consumption) in the Americas (EU) presents major challenges. In relation to goal 13 (Climate action), the countries facing the most challenges are in the Americas (USA, Canada, and Chile), although many European countries also present major challenges.

Thus, there are major challenges and challenges for a sustainable world. Further evolution is needed to achieve global sustainability. Although there are some specific objectives covered in some countries, there are still great challenges in the world to be covered. These challenges

Table 1a. Status of SDGs compliance: Economic dimension, according to sustainable development maps based on the global SDGs index according to global maps by goal [24].

Goal	Best- performing or challenges remain	Major Challenges remain and "Significant challenges remain"
1 End of poverty	The continent with the best results is Europe, followed by Asia, America, and Oceania. European countries and China have achieved the SDG target (green region in Figure 4). Countries in Africa (Morocco, Algeria, and Tunisia) have "challenges remaining" – (region highlighted in yellow).	The African continent is the one whose countries present the greatest challenges (major challenges remain - shown in cherry color) such as Senegal, Guinea, Sierra Leone, Cote d'Ivoire, Benin, Nigeria, Chad, Sudan, South Sudan, Central African Republic, Congo, Angola, Zambia, Mozambique, Uganda, Rwanda, Nigeria, Tanzania, Kenya, Madagascar, etc.)
2 Zero Hunger	**No country has** achieved the goal	There are still major challenges to be covered throughout the world. China presents evaluation as "Challenges remain" (Fig. 4-region amarilla). The other countries present both "Significant challenges remain" and "Major challenges remain". As is well known, the most critical continent is Africa, where almost all the countries have "Major challenges remain" (countries in cherry color in Figure 4).
3 Good Health and Well-being	**None of the world's countries** considers that it has achieved this goal. There are several countries that present "Challenges remain", i.e., in the scale of the report at a level to cover the goal. These countries are for example Japan, New Zealand, Norway, Denmark, United Kingdom, Iceland, Ireland, Spain, Portugal, Greece.	On the African continent, Algeria has "Significant challenges remain". All other countries are still facing "Major challenges remain" (colored cherry on the map). On the American continente: Mexico, Guatemala, Honduras, Nicaragua, Colombia, Venezuela, Guyana, Suriname, Ecuador, Peru, Bolivia and Paraguay. In Asia: Turkey, Jordan, Iraq, Iran, Afghanistan, Pakistan, India, Myanmar, Lao PDR, Vietnam, Cambodia, etc., among others. In Oceania with "Major challenges remain" is Papua News Guinea. In European countries (continent with better compliance) most of them are in a state of "Significant challenges remain".
8 Decent Work and Economic Growth	**None of the world's countries** considers that it has achieved this goal, although the best evaluated continent has been Europe.	The most critical situation is in Africa, followed by the Americas.
9 Industry, Innovation, and Infrastructure	**Japan** is the only country that has reached the goal (green color on the map). Although there are other countries in America (United States) and Europe (Iceland, Ireland, United Kingdom, Germany, Netherlands, France, Austria, Norway, Sweden, Finland) and even Asia (China and Korea) that are on their way to compliance since they are evaluated at the "Challenges remain" level.	The most critical situation is in Africa (more than 50% of the countries of the continent) followed by the Americas (Mexico, Honduras, Guatemala, Nicaragua, Costa Rica, Colombia, Venezuela, Guyana, Bolivia, Chile), these are rated as "Major challenges remain". Countries in Asia (India, Afghanistan, Pakistan, Myanmar, Cambodia) and Oceania (Papua New Guinea) share the same rating.

are diverse according to continent, country, culture, economic level, education, etc. The small improvement (9-13%) that has been achieved in the last 22 years (mainly before the Covid-19 period) is not enough.

In this sense it is required to integrate systemically, to establish strategies for evaluation, monitoring and feedback, for the design and redesign of international policy, governments, industry, corporate. In general, in the different stakeholders of the system called humanity, with their respective actors of the problem, which must play an active, permanent, and evolving role. Thus, the role of leaders (at home, in schools, in educational institutions, in the media, in government, in international associations, in radio, TV, digital networks, press, art in its various manifestations, influencers, etc.) will be important to permeate the information to sensitize peo-

Table 1b. Status of SDGs compliance: Economic dimension, according to sustainable development maps based on the global SDGs index according to global maps by goal [24].

Objetive	Best- performing or challenges remain	Major Challenges remain and "Significant challenges remain"
4 Quality Education	There are several countries with "SDG achieved", in the European continents (**Finland, Estonia, Russian Federation, Belarus, Serbia, Croatia**), the Americas (Canada, Peru, Argentina, Uruguay), and Asia (China, **Japan**, Korea, Vietnam, Mongolia, Sri Lanka, United Arab Emirates).	It should be noted that more than 50% of the countries in Africa are in "Major challenges remain" status
5 Gender Equality	The countries with an assessment as "SDG achieved" are **Argentina** (Americas), **Norway** (Europe), **Sweden** (Europe), **Namibia** (Africa) and **New Zealand** (Oceania).	The major challenges are found in countries on the African and Asian continents.
10 Reduced Inequality	It is the Asian country: **Japan,** the country that has reached the goal. However, countries such as Malaysia, China and Korea in Asia are also evolving towards this goal. On the European continent, Iceland, Ireland, Norway, Sweden, United Kingdom, France, Germany, Netherlands, and Denmark are evolving. The United States is also improving in the Americas.	Countries on the American continent, followed by countries in Africa, are the "Major challenges remain".
11 Sustainable Cities and Communities	**None country has reached the goal.** However, Countries have been evaluated with "Challenges remain": Americas (United States, Canada, Uruguay), Oceania (Australia and New Zealand), Asia (Japan, Korea, Malaysia), and Europe (Finland, Sweden, Norway, Denmark, United Kingdom, Ireland, Iceland, Switzerland, Spain, Portugal, France, Netherlands, Austria, Czech Republic, Hungary, Romania, Lithuania, Estonia, etc).	The African continent has major challenges to be covered in more than 50% of the countries that make up the continent.
16 Peace, Justice, and Strong Institutions	The countries in the world that have met this goal: in Asia **(Japan)** and in Europe **(Iceland)**.	Other countries that have advanced the fulfillment of this objective qualified as "Challenges remain" are: in America (Canada), in Oceania (Australia), in Europe (Portugal, Spain, Ireland, Italy, Germany, Belgium, Austria, Czech Republic, Poland, Greece, Slovenia, Latvia, Finland, Norway, Sweden, Georgia).
17 Partnerships	"SDG achieved" for **Norway** (region of the map in green).	Countries with major challenges to solve are in the Americas (United States, Canada, Venezuela), in Europe (United Kingdom, Ireland, Netherlands, Switzerland, Austria, Czech Republic, Poland, Latvia), in Asia (Japan, Korea, Myanmar, India, Afghanistan, Indonesia), in Oceania (New Zealand and Papua New Guinea) and in Africa (Mauritania, Mali, Guinea, Ivory Coast, Liberia, Chad, Sudan, Cameroon, Central African Republic, South Sudan, Somalia, Madagascar, Zimbabwe, Congo, Gabon).

ple at different holistic levels, at the corporate, community and individual levels, etc.; to adopt the changes that are so necessary (Figure 8.5). For this, they must also be sensitized and awaken awareness, which will require a new training of the leaders of the world (current and new) in their various holistic dimensions and roles, to help stop the destructive processes of humanity and its habitat. The formation received in informal and formal education will be determinant in the current and coming years. Education could be the central axis to achieve awareness of 1) The serious problems we face and what is projected if we do not act, 2) International agreements

Table 1c. Status of SDGs compliance: Economic dimension, according to sustainable development maps based on the global SDGs index according to global maps by goal [24].

Objetive	Best- performing	Major Challenges remain and "Significant challenges remain"
6 Clean Water and Sanitation	**None country** has achieved the goal.	"Major challenges remain" are in the Americas (Mexico, Nicaragua, Colombia, Bolivia), Africa (all countries except Morocco, Algeria, Egypt, Botswana, and South Africa which have "Significant challenges remain") and Asia (Mongolia, Cambodia, Myanmar, India, Pakistan, Afghanistan, Iran, Saudi Arabia, Yemen, Oman, etc.).
7 Affordable and Clean Energy	**"SDG achieved"** in South America (Brazil, Uruguay, Costa Rica) and Europe (Denmark, Finland, Norway, Portugal, Switzerland, Austria, Georgia, Iceland) and Oceania (New Zealand).	In Africa only Egypt, Gabon, Tunisia, and Ghana have "Significant challenges remain", all the others have "Major challenges remain". In Europe, countries such as Poland, Belarus, Russian Federation also have "Major challenges remain". In Asia, we have Kazakhstan, Uzbekistan, Turkmenistan, Mongolia, Cambodia, Myanmar among others.
12 Responsible Consumption and Production	**"SDG achieved"** in Americas (Guatemala and Honduras), Oceania (Papua New Guinea), Asia (Philippines, Cambodia, Korea, Lao PDR, Myanmar, Bangladesh, India, Nepal, Pakistan, Afghanistan, Uzbekistan, Yemen, etc), Africa (Madagascar, Mozambique, Zimbabwe, Zambia, Congo, Angola, Tanzania, Kenya, etc).	The countries were assessed as "still facing major challenges": in the Americas (United States), in Oceania (Australia and New Zealand), in Asia (Japan, Mongolia, Turkey), in Europe (Portugal, France, Germany, Netherlands, Austria, Sweden, Norway, Switzerland, Ireland, Greece).
13 Climate action	**"SDG achieved"** in America (Cuba, Guatemala, Honduras, Nicaragua, Bolivia), in Oceania (Papua New Guinea), in Asia (Cambodia, Korea, India, Nepal, Pakistan, Afghanistan, Yemen, Syrian Arab Republic, etc.) in Africa (Morocco, Mauritania, Senegal, Mali, etc.).	Countries in North America and Europe that still have major challenges to meet, are evaluated with" Major challenges remain"
14 Life below water	**None country** has achieved the goal. Only four countries worldwide have been assessed as on track to meet the "Challenges remain" objective Chile, Suriname, Namibia, and Congo.	Most countries in the world from all continents have an assessment as "Major challenges remain".
15 Life On Land	**"SDG achieved"** by Poland, Lithuania, and Estonia.	In the Americas and Asia, almost all countries are evaluated with "Major challenges remain" and fewer countries with "Significant challenges remain". Africa is in the same situation with "Major challenges remain" and with "Significant challenges remain". Objective 15 is the goal that needs the most work in the world.

that have existed in the last 50 years and those that will be added, 3) Actions and technologies to be used according to what has been generated and will continue to be generated in the scientific

Figure 8.5: *Transdisciplinarity for sustainability Transdisciplinary attitudes based on what is mentioned by some authors [32-40]*

community.

Basarab (1996) mentioned that transdisciplinary culture is impossible without a new type of education that takes into account "all" dimensions of the human being, including the spiritual dimension (Basarab, 1996) [29]. The world problem is partly a problem of awareness in humanity: among world leaders and society. They could define a shared vision as recommended by Meadows (2001) [30] to achieve the survival of the human species. Peter Senge [31] refers to the shared vision as uniting people around a common identity and aspiration; but it is not an idea, but rather a force inspired by an idea that will motivate the members of the organization to act. In this case the organization would be humanity and we would all have to develop a will, a driving force inspired by the idea of achieving a sustainable world.

Then, the transdisciplinary culture could be the methodology that supports the path towards sustainability, since it touches the subject that investigates and society in a constant process of self-investigation and self-transformation, which would lead to conscious and sustainable evolutionary attitudes. Therefore, one of the great challenges in education will be that trainers learn to transform themselves and teach students to transform themselves. In this way the transdisciplinary methodology involving spiritual, religious, or cultural development [32,33], could cultivate attitudes that lead to the way to be sustainable through Self-investigation - Self-transformation Observation, Ethics, Reflections, Transformation, Awareness, Empathy, Openness, Tolerance, Rigor, Dialogue, Collaboration, Integration, Resilience, Patience, Prudence, Shared vision, Integration, Moderation, among others [32,41].

In closing we would like to recall what Jan Forrester said more than 50 years ago:

> "A global equilibrium is conceptually possible. The actions that would be necessary for it are not easy to accept. It will probably take more pressure on humanity from the environment before such issues are taken with sufficient concern and seriousness. However, by then the time available for action will be even shorter (Forrester, 1971, see Rodriguez, 2011)." [23].

If we recall Rapetto's 1986 definition of sustainable development which states that it is: "a development strategy that manages all assets, natural resources, and human resources, as well as financial and physical assets, for increasing long-term wealth, and well-being" (Rapetto (1986), cited in Touson (2001) [43]. Then, international politics and governments in their nations still have great challenges to face by assuming orientations in adherence to the global warming in the planetary situation due to human actions.

> I tried to change the world and I couldn't
>
> I change myself
>
> and change the world (**Mahatma Gandhi**)

8.4 Conclusions

The continents (American, European, Asian, African and Oceania) have had the highest growth of the SDG indicator in the period 2000-2019 (pre-pandemic period), with slight changes during the 20020-2022 pandemic. The continent with the highest growth (2000-2022) in the indicator is Africa (13.31%), although it has the lowest average indicator value compared to the other continents. The pandemic had an impact on the sustainable development index.

There are goals for each dimension of sustainability that have not yet been achieved by any country in the five continents: 1) Environmental dimension: 14 Life below water, 6 Clean Water and Sanitation; 2) Social Dimension: 11 Sustainable Cities and Communities, and 3) Economic dimension: 8 Decent Work and Economic Growth, 3 Good Health and Well-being y 2) 2 Zero Hunger.

The countries with the highest SDGs in the last 22 years in each continent are: European (Finland, Denmark, Sweden, Norway), American (Canada, Chile, and Uruguay), Asian (Japan and Korea), Oceania (New Zealand) and African (Algeria, Egypt Arab Rep). The countries with the lowest index values per continent are European (Uzbekistan, Tajikistan, Montenegro, Turkey, Albania), American (Haiti, Guatemala, Honduras, Guyana, Venezuela, Panama), Asian (Afghanistan, Yemen, Pakistan, India), Oceania (Papua New Guinea) and African (South Sudan, Chad, Central African Republic, Somalia).

The role of formal and informal education will be relevant in the coming years. Transdisciplinarity could be a methodology that would allow us to move towards sustainable development in humanity, to the extent that we work in different dimensions and with different leaders, from

politicians, government leaders, businessmen, representatives of civil society, researchers, teachers, etc.

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About the Authors

Claudia Hernandez-Aguilar is a professor and researcher at the National Polytechnic Institute, within the Graduate Program in Systems Engineering of ESIME Zacatenco. She is the leader of the Research Group on Sustainable Biophysical Systems for Agriculture, Food, and Medicine. She is a member of the Mexican Academy of Sciences and the National System of

Researchers (Mexico). Since 2012, she has been a member of the Editorial Committee for the International Agrophysics journal. She has published her research in international journals and has received over 550 citations in Scopus. Her focus is the use of engineering e.g., sustainable biophysical methods and photothermal techniques to improve society's quality of life and well-being. In times of pandemic and post-pandemic, she has proposed educational interventions for the consumption of nutraceutical and low glycemic index foods, as well as the care of the other, the other, and the others. She has trained young transdisciplinary researchers for the past 15 years, emphasizing the need for awareness, conscience, rigor, and humanism in the research process and of a Transdisciplinary systemic view on the impact obtained from it. Motto: Transform yourself, to transform your world.

Francisco Suazo López is a Professor at the University of Chapingo, within the Department of Agricultural High School. Agronomy Area. Current PhD student in Systems Engineering-ESIME-Zacatenco-IPN. He has given training courses in hydroponics and greenhouse management. He has also developed projects related to the establishment and management of crops both in the field and in greenhouses. Specialist in drip irrigation design. He participates with producers to learn about their needs and propose alternatives to improve their production.

Dr. F. Arturo Dominguez Pacheco, Doctorate in Systems Engineering with a postdoctoral degree in PHYSICS from Cinvestav, Mexico (two periods). Research Professor of the Postgraduate Program in Systems Engineering at ESIME-Zacatenco-IPN in the line of research in Engineering Systems. Member of the Research Group on Sustainable Biophysical Systems (SBS) for Agriculture, Food and Medicine. Main scientic contributions in Characterization of Materials and Development of Irradiator Prototypes. Active collaborator and participant in research projects with the Cinvestav. Photothermal Techniques group, as well as Director of research projects at the IPN since 2010. Currently SNI level I of the area VI.