EFFECTS OF PRE-SOWING INCUBATION WITHIN A PYRAMID ON GERMINATION AND SEEDLING GROWTH OF PHASEOLUS VULGARIS L.

A Thesis

by

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Abstract

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Food is crucial for all life on the planet, however food security is a problem in many parts of the world (Van Straaten, 2006). In the last decade the number of undernourished grew to 1.02 billion (FAO, 2009). Shapouri et al. (2010) estimates by 2020 food insecurity will reach 500 million in SSA. In a world with limited resources, the only solution to meet food demand is by maximizing yield per unit of land (Van Straaten, 2006). Large-scale intensive farming is widely practiced in the US as a solution to this growing problem (Fyfe et al., 2006). Current food production practices are driven by mass production, which is highlighted by large inputs including pesticides, fertilizers, and irrigation. Although these techniques have revolutionized agriculture and helped combat world hunger, ill effects have been reported such as soil degradation and loss of biodiversity (Tilman et al., 2002). Alternative techniques can be introduced which increase plant production and are environmentally friendly, less costly, and less intensive (Theodoro & Leonardos, 2006). Two of these methods are magnetic fields and radiation (Aladjadjiyan, 2012). Magnetic fields were confirmed to affect plant growth, germination, metabolism, and vigor (Celik et al., 2009; Zuniga et al., 2016).

Literature suggests pyramidal shapes harness the magnetic field of the earth to generate para magnetism within their structure (Van Doorne, 2013). Although pyramids have produced documented improvements in plant growth and germination (Kumar et al., 2010), the use of pyramids to incubate seeds before planting has not been tested. The purpose of this research was to describe the impacts of pre-sowing incubation within a pyramid on germination characteristics, seedling growth, seed desiccation, and soil condition, as well as describe any relationships existing between independent and dependent variables. Both wooden and copper pyramids were used, and seeds were incubated for periods of 5, 10, 35, and 45 days. A total of 1,800 seeds were tested. Data were analyzed in SPSS using one-way ANOVA's at $p<.05$ significance level. Pyramids negatively affected germination frequency, percentage, time, and rate, but positively affected uniformity (synchrony, uncertainty, variation of germination time). Conclusions indicate longer incubation periods are beneficial for germination and uniformity, while shorter incubation periods increased vegetative growth. Copper pyramids exceled over wooden pyramids when examining seedling growth. Copper pyramids paired with longer incubation periods saw the highest increase in seed weight. The highest average soil temperature was recorded in the wooden pyramid, and soil pH remained unchanged.

Nomenclature

AOSA	Association of Official Seed Analysts
ANOVA	Analysis of Variance
Ca	calcium
CGS	centimeters-grams-seconds
FAO	Food and Agriculture Organization
GA3	Gibberellic Acid
ISTA	International Seed Testing Association
K	potassium
MDA	malondialdehyde
Mg	magnesium
N	nitrogen
P	phosphorus
PCSM	Para magnetic Count Soil Meter
SPSS	Statistical Package for the Social Sciences
SSA	Sub-Saharan Africa
TDA	Texas Department of Agriculture
TBARS	Thiobarbituric acid reactive substances
US	United States
UV	Ultraviolet

TABLE OF CONTENTS

LIST OF GRAPHICS .... **x**

CHAPTER I **1**

INTRODUCTION 1

Introduction 1

Objectives 6

Hypotheses 7

Significance of the Study 8

Scope and Limitations 9

CHAPTER II **10**

LITERATURE REVIEW 10

Introduction 10

Emergence of Pyramid Research 11

Scientific Pyramid Research 14

Effects of pyramids on plants 14

Effects of pyramids on health 16

Effects of pyramids on liquids 17

The Great Pyramid of Giza 18

Constructing and Using a Pyramid 19

Physical Methods of Increasing Plant Growth 24

Introduction 24

Magnetism 25

Magnetic treatment of plants and seeds 26

Magnetic treatment of water 28

Para magnetism 30

Seed Physiology 32

CHAPTER III 36

MATERIALS AND METHODS 36

Research Design 36

Pyramid Construction 39

Pyramid Set Up 41

Mathematical Equations 42

Germination percentage 42

Mean germination time 42

Coefficient of variation of germination time 43

Mean germination rate 44

Uncertainty of the germination process 45

Synchrony of germination 45

Tissue water content 46

Change in seed weight 47

Assumptions 47

Statistical Analysis 48

CHAPTER IV 51

RESULTS 51

Objective 1 Results 51

Objective 2 Results 54
Objective 3 Results 56
Objective 4 Results 56
Objective 5 Results 58
Objective 6 Results 59
CHAPTER V 60
CONCLUSIONS......60
Conclusions......60
Objective 1 conclusions 60
Objective 2 conclusions 62
Objective 3 conclusions 62
Objective 4 conclusions 63
Objective 5 conclusions......63
Objective 6 conclusions 64
Implications......65
Objective 1 implications 65
Objective 2 implications 66
Objective 3 implications 66
Objective 4 implications 67
Objective 5 implications 67
Objective 6 implications 68
Recommendations......68
Objective 1 recommendations......68

Objective 2 recommendations...69

Objective 3 recommendations...69

Objective 4 recommendations...70

Objective 5 recommendations...70

Objective 6 recommendations...70

REFERENCES...72

APPENDICES..85

APPENDIX A...86

APPENDIX B...88

APPENDIX C...90

APPENDIX D...93

APPENDIX E...95

APPENDIX F...97

LIST OF GRAPHICS

TABLE **Page**

1. Para magnetic values of soil measured in CGS 30
2. Pyramid specifications 39
3. Formula limits and units of measure....48
4. List of variables and corresponding abbreviations, descriptions, and coding 49
5. Resulting values from Levene's test for equality of error variances 50
6. Resulting values from Shapiro-Wilk's test of normality 51
7. Mean frequency of seed germination of *Phaseolus vulgaris* seeds incubated....52
8. Descriptive statistics of germination measurements of *Phaseolus vulgaris* seeds after incubation under pyramids of varying materials 53
9. Descriptive statistics of germination measurements of *Phaseolus vulgaris* seeds after varying incubation periods within a pyramid 54
10. Descriptive statistics of seedling growth of *Phaseolus vulgaris* seeds after incubation under pyramids of varying materials 55
11. Descriptive statistics of seedling growth of *Phaseolus vulgaris* seeds after varying incubation periods within a pyramid....55
12. Descriptive statistics of desiccation of *Phaseolus vulgaris* seeds after incubation under pyramids of varying materials 56
13. Descriptive statistics of desiccation of *Phaseolus vulgaris* seeds after varying incubation periods within a pyramid....57
14. Descriptive statistics of soil temperature after incubation within a pyramid....57

15. Comparative analysis of soil temperature among varying pyramid materials..58
16. Impact of varying pyramid materials on germination characteristics..............59
17. Length of pre-sowing incubation impacts on germination characteristics 60
18. Schedule of activities 91
19. Total number of germinated seeds, moldy germinated seeds, and non-germ...94

FIGURE **Page**

1. Measurements used to construct a pyramid 21
2. Germination and growth process of beans 34
3. Wooden pyramid...40
4. Copper pyramid 40
5. Pyramid one third height and alignment to magnetic north...............41
6. Germination percentage 42
7. Mean germination time 43
8. Variance of germination time 43
9. Coefficient of variation of germination time 44
10. Mean germination rate 44
11. Relative frequency of germination...45
12. Uncertainty of the germination process 45
13. Combination of seeds germinated..46
14. Synchrony of germination...46
15. Tissue water content 46
16. Change in seed weight 47

17. Phi value in a triangle 87

18. Phi value in a pyramid replica of the Great Pyramid of Giza 87

19. Phi calculation..........87

20. Pi calculation..........87

21. Infrared thermal image of wooden pyramid 96

22. Infrared thermal image of copper pyramid 96

23. Mean germination percentage of seeds sorted by pyramid material and..........98

24. Mean germinating time of seeds sorted by pyramid material and incubation ..99

25. Mean coefficient of variation of germination time of seeds sorted by 100

26. Mean germination rate of seeds sorted by pyramid material and incubation ...101

27. Mean uncertainty of germination of seeds sorted by pyramid material and.....102

28. Mean synchrony of germination of seeds sorted by pyramid material and 103

29. Mean tissue water content of seeds sorted by pyramid material and..........104

30. Mean percent change in weight of seeds sorted by pyramid material and 105

31. Frequency distribution of soil temperature measured under pyramids of 106

CHAPTER I

INTRODUCTION

Introduction

Food is crucial for all life on the planet, however, food security is a very real problem in many parts of the world (Van Straaten, 2006). As of 2016, the world population is now over 7.3 billion (Cumming, 2016). This growing population has two primary consequences: food insufficiency and growing energy consumption (Aladjadjiyan, 2012). According to Shapouri, Peters, Allen, Rosen, and Baquedano (2010), food insecurity is defined as those consuming less than 2,100 calories per day. In the last decade global hunger has risen and the number of those who are undernourished grew to 1.02 billion in 2009 (FAO, 2009). Food security is a delicate situation, as a short-lived decrease in food production could send millions more tumbling into food insecurity (Shapouri et al., 2010). Developed countries are also not immune from food shortages and fluctuating food prices. Although the food crisis of 2008 largely affected developing nations, the effect was felt globally (FAO, 2009). In a survey conducted of 180 food banks in America, 99% reported an average increase of 15-20% in the number of people seeking assistance, with most citing rising food and fuel prices as the dominant factors driving the increase (America's Second Harvest, 2008).

Today, sub-Saharan Africa (SSA) is suffering from a net decline in per capita food production. While local agricultural production is increasing, it is not increasing quickly enough to meet the demand (Van Straaten, 2002). Shapouri et al. (2010) estimates by 2020 food insecurity will reach 500 million people of a total 1 billion in

SSA. Coincidentally, agriculture accounts for the livelihood and primary income source of more than 50% of the population in SSA. Poverty is defined as earning less than $1 per day, and about half of African farmers are considered poor by this definition (Van Straaten, 2002). In SSA, extension agents and non-governmental organizations are promoting market-oriented agriculture to help reduce the poverty level (Hogh-Jensen, 2011). One problem with this intensive agricultural approach is soils are being ‘mined’ and stripped of their nutrients in an effort to feed the growing population (Van Straaten, 2002; Van Straaten, 2006). The other issue is not all farmers are able to innovate due to high prices and limited input availability. Despite these drawbacks, intensive agriculture is still helping to combat local food insecurity in SSA (Hogh-Jensen, 2011).

While developing countries are struggling to combat hunger by intensifying local production, developed countries such as the United States (US) and those in Europe are consuming more than their fair share of world agricultural food production (Fyfe, Leonardos, & Theodoro, 2006). This level of consumption cannot be sustained in a world with limited resources, thus the only solution is to maximize crop production per unit of land (Van Straaten, 2006). Large-scale intensive farming has been widely adopted in the US as a solution to this growing problem (Fyfe et al., 2006). Intensive farming is characterized by market orientation and monoculture. Modern agriculture has come a long way from the days planting and harvesting crops by hand. Mechanization increased dramatically with the Industrial Revolution and has significantly increased farming and production capabilities, specifically in terms of acreage, as labor inputs are no longer a limiting factor for farmers. Current food production practices in the US are driven by mass production which is highlighted by large inputs including pesticides, fertilizers, and irrigation. In addition, genetic engineering has helped increase yield per acre, combat nutritional deficiencies, and is helping feed those in poverty in developing countries. Although these new techniques have revolutionized agriculture, some ill effects have been reported such as soil degradation, loss of biodiversity, lack of crop rotation, and decrease in soil potential from loss of nutrients. The massive import/export commodities markets have also exacerbated water shortages through virtual water trade. Intensive farming has become unsustainable as the production costs of modern agriculture have begun to outlive their benefit (Fyfe et al., 2006). This can be seen by the widespread subsidies present in American agriculture and the biodiversity loss among habitats (Tilman, Cassman, Matson, Naylor, & Polasky, 2002).

A main component contributing to the unsustainability of modern agriculture is the use of artificial chemicals as fertilizer, the use of which has increased abruptly since adoption at the end of World War II (Foster & Magdoff, 1998; Smil 2001). Baranski et al. (2014) conducted an in-depth study of organic and conventional crops and concluded the use of artificial products for fertilization resulted in decreased antioxidant levels as opposed to organic. When chemicals were introduced to tropical countries, areas with record yields also saw loss of topsoil and deforestation (Theodoro & Leonardos, 2006). Attempts to improve production and soil fertility through added chemicals perpetuates a never-ending cycle of chemical application and dependence (Aladjadjiyan, 2012), and inappropriate use of chemicals can even result in low crop yield and productivity. In addition, the use of chemicals is an expensive and short-term fix to the problem of food security (Van Straaten, 2002). Van Straaten (2006) notes fertilizers, pesticides, and herbicides are reliant upon fossil fuels which further increases production prices for farmers as well as our impact upon the environment.

As many people in the world are struggling with food security, obtaining sufficient amounts of protein is a naturally reoccurring problem. Known as *Phaseolus vulgaris*, beans are exceptionally important to people in poor areas of the world for providing protein to supplement low meat availability (Broughton et al., 2003; Onchabo, 2002). Beans are a major grain legume crop, falling third only behind soybeans and peanuts in the Unites States (Broughton et al., 2003). According to Lewis, Schrire, Mac Kinder, and Lock (2005), leguminous plants (*Fabaceae*) are an economically important family of flowering plants due to large cultivation and consumption in the world. Plants in the *Fabaceae* family grow in many different climates and are largely harvested for hay and animal feed in addition to human consumption (Sujak, Dziwulska-Hunek, & Reszczynska, 2013). Beans are also important agricultural plants due to their nitrogen fixation capabilities and ability to produce normal to high yields without synthetic nitrogen additives (Sujak et al., 2013). Nitrogen is a necessary soil nutrient for all food production and according to Erisman, Sutton, Galloway, Klimont, and Winiwarter (2008), one way of providing this is Haber-Bosch nitrogen, also known as synthetic nitrogen. The other way to produce food without using fossil fuels is through leguminous plants (Giller, 2001). A combination of these two techniques is largely meeting world food demand with each method feeding half the population (Hogh-Jensen, 2012). In Kenya the combination of synthetic fertilizers and poor farming techniques has led to low bean yield, thus contributing to low protein availability and malnourishment (Odhiambo, Ndiritu, & Wagara, 2009).

In order to effectively combat world hunger and increase production levels with less arable land, alternative measures should be introduced while maintaining an awareness of the environment (Bialis et al., 2013). These alternative measures are characterized by minimal external inputs (Ingram, 2007). Physical factors include magnetic fields, electromagnetic fields, electric fields, UV radiation, light radiation, heat, lasers, microwave radiation, ultrasound, and ionized radiation (Aladjadjiyan, 2012; Rajasekhar, Nagaraju, Reshma, & Kumar, 2011). These techniques are safer, environmentally friendly, sustainable, and inexpensive in comparison to chemical measures (Theodoro & Leonardos, 2006). These alternative techniques also meet requirements for organic agriculture and are widely applicable in alternative farming practices. Magnetic and electromagnetic treatment of seeds was shown to be a non-invasive technique to increase yield (Martinez, Florez, Maqueda, Carbonell, & Amaya, 2009). Low germination activity of seeds is a significant problem in agriculture (Pietruszewski, Muszynski, & Dziwulska, 2007). Zuniga, Benavides, Ospina-Salazar, Jimenez, and Gutierrez (2016) add that magnetic fields can stimulate germination, vigor, and growth rate. Magnetic treatment of water has shown positive effects on plants and could be promising as an addition to these methods (Zuniga et al., 2016).

A lesser known and implemented technique used to influence plant germination and growth is para magnetic (low intensity) force. Volcanic rock is the most prevalent technique used to introduce para magnetism in agriculture and has shown positive effects on soil and plants (Callahan, 1995). It is hypothesized that pyramids, similar to volcanic and para magnetic rocks, use the magnetic field of the earth to generate a para magnetic field within their structure (Brown, 1978; Van Doorne, 2013). Some also suggest pyramids may combine both magnetic and electric forces resulting in a pyramid-induced electromagnetic field (Toth & Nielson, 1974). Although pyramids have produced documented improvements in plant growth and germination (Kumar, Swamy, Nagendra, & Radhakrishna, 2010), the use of pyramids to incubate seeds before planting has not been adequately tested.

In Belgium Van Doorne (2013) uses pyramids to store grain and has seen improvements in germination, pest control, and seed viability. Van Doorne (2013) conducts seminars to teach the public about using pyramids in agriculture, but proof of positive effects has not been widely studied or evaluated in a statistical or scientific manner. Use of this technique could have tremendous impacts on agricultural yield and food insecurity, thus it is necessary to scientifically examine the effects of pyramids on seeds. There are many websites selling pyramids for this and other purposes, and it is even possible to make your own pyramid. However, different sources have provided contrasting specifications and varying protocols for implementing this method. An in-depth examination of literature provided a pattern of common beliefs regarding size and shape of the pyramid to be followed in order to obtain beneficial effects, and therefore all following research was based on these specifications.

Objectives

The purpose of this research was to evaluate how pre-sowing incubation within pyramids impacted germination and seedling growth of *Phaseolus vulgaris* seeds. More specifically, the following objectives were used to guide data collection and analysis:

(1) Describe the impact of pre-sowing incubation within a pyramid on germination characteristics (G, MGT, CV_t, MGR, U, Z).

(2) Describe the impact of pre-sowing incubation within a pyramid regarding seedling growth.

(3) Describe the impact of pre-sowing incubation within a pyramid regarding desiccation of seeds, serving as a germination trigger.

(4) Describe the impact of pyramid presence and construction material regarding soil condition.

(5) Describe any linear relationship existing between pyramid construction material, germination characteristics, seedling growth, and seed weight.

(6) Describe any linear relationship existing between length of pre-sowing incubation period, germination characteristics, seedling growth, and seed weight.

Hypotheses

The alternative hypotheses and null hypotheses for each objective are as follows:

H_1 – Pre-sowing incubation within a pyramid will have an effect on germination characteristics.

H_{0a} - Pre-sowing incubation within a pyramid will have no effect on germination characteristics.

H_2 - Pre-sowing incubation within a pyramid will have an effect on seedling growth.

H_{0b} - Pre-sowing incubation within a pyramid will have no effect on seedling growth.

H_3 - Pre-sowing incubation within a pyramid will have an effect on seed weight.

H_{0c} - Pre-sowing incubation within a pyramid will have no effect on seed weight.

H_4 - Pyramid presence and construction material will have an effect on soil condition.

H_{0d} - Pyramid presence and construction material will have no effect on soil condition.

H_5 - A relationship will exist between pyramid material and germination characteristics.

H_{0e} - A relationship will not exist between pyramid material and germination characteristics.

H_6 - A relationship will exist between pyramid material and seedling growth.

H_{0f} - A relationship will not exist between pyramid material and seedling growth.

H_7 -A relationship will exist between pyramid material and seed weight.

H_{0g} - A relationship will not exist between pyramid material and seed weight.

H_8 - A relationship will exist between length of incubation period and germination characteristics.

H_{0h} - A relationship will not exist between length of incubation period and germination characteristics.

H_9 - A relationship will exist between length of incubation period and seedling growth.

H_{0i} - A relationship will not exist between length of incubation period and seedling growth.

H_{10} - A relationship will exist between length of incubation period and seed weight.

H_{0j} - A relationship will not exist between length of incubation period and seed weight.

Significance of the Study

Although many tests have been conducted on pyramids in recent years, the knowledge base is still quite elementary. This empirical study will contribute to the body of literature existing on the subject and provide clarification of the methods and techniques that should be used. I took priority in examining and comparing ideologies of the pyramid technique in order to provide farmers and researchers with information needed to conduct tests of their own. This research will also provide clarity on the use of pyramids in agriculture. Significant results in germination and seed vigor would have enormous impacts for farmers and ranchers who are seeking to increase crop yield without using chemical fertilizers. This would save farmers time and money, and help to maximize profit from their operations. The use of pyramids to incubate seeds is much more practical than growing plants under pyramids due to capacity and other limitations.

Scope and Limitations

Amidst the expansive collection of known plant species in North America, this study was centralized around *Phaseolus vulgaris* (field bean), specifically bush beans of the pinto variety. While pinto beans were easier to grow indoors in a laboratory setting, perhaps corn, soybeans, cotton, sorghum, or wheat would have had more relevance for farmers in North America. Due to available time within the chosen program of study, it was not possible to conduct a long term experiment. This would have provided insightful data on maturity of the bean plants and an opportunity to examine all stages of growth. Due to limited space and greenhouse area, the study was conducted indoors. This could alter the presence and effect of magnetic energy. Because use of pyramids is a relatively new topic, magnetism of the earth has not been scientifically established as the source of positive effects obtained from using pyramids. With cited positive results, future research would be needed to validate this claim. Because there are also certain specifications needed to properly build a pyramid, the data and results are only as good as the accuracy of pyramid construction.

CHAPTER II

LITERATURE REVIEW

Introduction

Adoption and use of sustainable farming techniques is the key for improving soil health and feeding the worlds growing population (Van Straaten, 2002). While chemicals are used as a quick-fix to alleviate food insecurity, there are other ways of increasing plant production which are environmentally friendly, less costly, and less intensive (Van Straaten, 2006). Two of these methods are magnetic fields and electromagnetic waves (Aladjadjiyan, 2012). Two lesser known similar techniques are introducing para magnetism through use of volcanic rock, and using pyramids. The pyramidal shape has been hypothesized to use earth's magnetic field to generate para magnetism within its' structure, thus combining both techniques equates to better utilization of these energies for plant growth (Flanagan, 1973; Van Doorne, 2013). While access to magnetic and electromagnetic technologies could be limited in the global areas where they are most needed (SSA for example), pyramids are a cheaper and potentially more efficient alternative. Therefore, the use of pyramids could have tremendous implications for agricultural production and needs further research and experimentation. The knowledge and techniques of using pyramids are quite specific and much clarification is still needed on the subject.

Emergence of Pyramid Research

While scientific testing regarding the impact of pyramids on agricultural production has only begun in recent years, home experiments began in the 1970's on topics such as plant growth, water, food dehydration, and health. In the 1930's, a Frenchman named Antoine Bovis was visiting the Great Pyramid of Egypt when he observed the dead animals inside having been preserved instead of decaying. Upon seeing this, Bovis conducted numerous at home experiments with Great Pyramid replicas and concluded pyramids were capable of dehydrating food and sharpening razor blades. After reviewing these claims, Czechoslovakian radio engineer Karl Drbal conducted his own experiments with pyramids (De Salvo, 2003; Flanagan, 1973; Schul & Pettit, 1975; Toth & Nielson, 1974). This led to his 1959 patent of "Cheops Pyramid Razor Blade Sharpener" (Drbal, 1959; Flanagan, 1973). Drbal claimed a pyramid could extend a razor blades life to 200 shaves. Flanagan (1973) tested this claim but discovered de-ionized water had the same effect on the razor blades as the pyramid. Thus Flanagan hypothesized that rather than sharpening the razor blade, the pyramid was actually preventing the blade from becoming dull.

Flanagan (1973) also conducted experiments with pyramids using alfalfa sprouts by placing the plants inside the pyramid, placing seeds inside the pyramid before planting, and by storing his irrigation water inside the pyramid. In all cases, the pyramid plants saw growth 2-3 times faster than the control, and sprouts were healthier and lasted longer when harvested. Flanagan concluded the water and direct plant treatments saw the best results, with seed treatment being the least beneficial. Brown (1978), however, did not have favorable results from growing seedlings directly inside a small wire pyramid.

Schul and Pettit (1975) started tomato plants inside a pyramid and later transplanted them outside. The result was an increase in production over the controls, but they noted results from using pyramids is not always consistent. As Schul and Pettit caution, seeds within a pyramid sometimes see slower germination than normal and do not always germinate. Van Doorne (2013) asserts energizing seeds is the simplest and most effective way for a farmer to boost the fertility of their land with potential to double the harvest. Van Doorne believes some Mayan tribes stored seeds on top of pyramids each year to energize them.

Toth and Nielson (1974) verified that seeds stored within a pyramid before planting show quicker germination time and rate and produce a healthier plant. Brown's (1978) findings conform to this statement, and he expressed when pyramids are used to store grain, insect infestation will be minimal or even eliminated. It is also believed water stored inside a pyramid stimulates plant growth, similar to fertilizer, and freshly cut flowers last longer in this water (Flanagan, 1973; Toth & Nielson, 1974). Toth and Nielson (1974) suggest water stored within a pyramid actually undergoes a structural change, and Flanagan (1973) believes pyramid treated water has less chlorine taste, but these claims need to be evaluated with further research.

Experiments with dehydration were conducted as well following claims made by Bovis that food placed anywhere within a pyramid would be preserved (Brown, 1978; Flanagan, 1973; Schul & Pettit, 1975; Toth & Nielson, 1974). Brown (1978) asserted an egg could be dehydrated within the pyramid and later reconstituted with water and eaten with no loss of nutrients or taste. Flanagan (1973) confirmed dehydration is a natural process but the pyramid environment prohibits decay and bacterial growth. In his own experiments with food products, Flanagan (1973) noted effective preservation of hamburger meat, liver, eggs, and milk, and documented better taste, specifically sweeter sweets and less acidic bitter and sour foods. Van Doorne (2013) noted pyramids can be used to keep food fresh and to boost the taste and nutrition of water, wine and food. In the area of health, early experiments with pyramids noted relief from migraine headaches and depression, increased healing of cuts and wounds, relief of insect stings, and made it easier to reach alpha state meditation (Brown, 1978; Flanagan, 1973).

Brown (1978) was the first person to propose the idea of using pyramids for large-scale food production, and believed pyramids could cure the food shortages plaguing our world. Brown designed a 30-foot pyramid greenhouse with three floors, and soon became known in the area for the substantial size of his produce. His garden serving as an experiment, Brown observed larger leaves, blooms, and fruit, higher yield, and larger plant size. Pyramid tomatoes produced 50-60 pounds per plant while the control yielded 10-14 pounds; pyramid cabbage weighed 12-13 pounds per head while the control weighed 3 pounds on average; pyramid-grown cucumbers grew up to 20 inches long while control plants averaged 14 inches; lettuce was 2-3 times larger than average, and beans were 25 inches long at harvest. Brown also determined seeds in his pyramid greenhouse germinated the fastest on the second floor (three days), averaging two days faster than other locations inside his pyramid.

Scientific Pyramid Research

Although most of the above claims about the use of pyramids were conducted in at-home unpublished experiments, a fair number of scientific studies have been conducted on the subject. The most commonly researched areas are regarding the use of pyramids for health, food, and plant growth. Most if not all of these experiments have concluded positive effects from using pyramids.

Effects of pyramids on plants

Experiments with plants have shown consistent results documenting improvements in plant germination and growth under pyramids. DeSalvo (2003) showed pyramids increased crop yield 20-100%, and crops were largely unaffected by drought. Vasavada and Gadani (2012) germinated peas, chickpeas, mung beans, and moth beans under cardboard pyramids. Radicle emergence in three of the four seed types occurred after 24 hours in the pyramid samples, while all control groups germinated after 48 hours. Pyramid groups displayed higher germination percentages over the control groups up to 72 hours, after which the control groups nearly equaled or surpassed them.

Kumar et al. (2010) compared wooden square and plywood square pyramids on germination of fenugreek. Both pyramids had higher average temperature than the control. Seed samples had a higher germination percentage and mean radicle emergence was significant ($p < .001$). Pyramid groups saw higher fresh and dry weights, and seedling vigor was significant for the wooden ($p < .003$) and plywood ($p < .004$) pyramids. Overall, the wooden square pyramid saw the highest benefits in radicle length, seedling vigor, and germination percentage.

Kumar and Nagendra (2011) evaluated the influence of fiberglass octagonal and square pyramids on fenugreek. Seed emergence was higher in the fiberglass square pyramid, followed by the fiberglass octagonal pyramid and the control. The highest radicle dry weight was measured in the pyramids (square over octagonal), and emergence was 97% for both pyramids while the control saw 95% emergence. Average temperature measured was higher in both pyramids over the control. The square pyramid had the highest seedling vigor dry weight followed by the octagonal pyramid and the control.

Kuzmina, Narenova, and Espenfetova (2013) planted *Phaseolus vulgaris* L. seeds under three pyramids of varying dimensions, which were constructed from metal wire and cellulose film. Beans planted under the pyramids fully germinated on the fourth day, while the control group germinated on day six. Germs under the pyramids, on average, were taller and stronger, and thus it was concluded pyramids increased the germination capacity and growth of germs. Germs from all three pyramids were disease free.

Narimanov (2001) stored barley seeds in a cardboard pyramid for five days. Differences in germination were significant ($p < .05$) and growth of pyramid plants proceeded more intensely than the control, resulting in higher average plant length. Narimanov also studied the effect of water kept in a pyramid on seed and plant growth. The pyramid water retarded plant growth and had higher acidity levels than normal. Following this conclusion, he experimented with barley seeds and quartz granules to see if weight changed under the pyramid. The seeds lost moisture 1.8 times faster and the quartz lost moisture 1.6 times faster than normal. He replicated the study using polyethylene bags to store the barley and quartz, and no weight changes were detected.

Narimanov concluded seed desiccation is enhanced by pyramids which results in increased germination speed.

The studies above outlined effects obtained from using pyramids on seeds and plants. Results indicate pyramids can enhance seed desiccation, germination, growth rate, and fresh and dry weights. Pyramids also seem to have a higher average temperature which may be influencing plant growth. It is evident that pyramids may be used in agriculture to increase food production and help reduce world poverty and hunger.

Effects of pyramids on health

It has been shown that pyramids are able to counteract stress, increase the rate of healing, and combat tumor development in rats. Researchers in Russia have conducted experiments on the ability of immunoglobulins to fight infections, viruses, and bacteria, and results indicate pyramids increased the ability of immunoglobulins to fight viruses by more than three times (DeSalvo, 2003). Experiments conducted by Nahed, Salwa, Abdel, Hadary, and Gehan (2010) concluded rats housed in pyramids saw less cancer development and smaller tumor size, and lower levels of liver enzymes, protein, and thyroid hormones ($p < .05$) than rats housed in normal cages.

Bhat, Rao, Murthy, and Bhat (2003) concluded housing of female rats within pyramids reduced neuroendocrine stress and increased antioxidant defense, which in turn reduced oxidative stress. Indicators of oxidative defense were higher in pyramid groups ($p < .001$) and these groups showed lower levels of MDA in erythrocytes ($p < .01$). Plasma cortisol levels were significantly lower in pyramid-exposed groups ($p < .05$).

Bhat, Rao, Murthy, and Bhat (2006) experimented with different cage shapes and concluded restraint-induced increases in plasma cortisol levels were counteracted by pyramid exposure. Plasma cortisol was significantly lower in pyramids than the control group ($p < .05$) and Erythrocyte TBARS levels were also significantly lower than the control group ($p < .001$). Murthy, George, Ramasamy, and Mustapha (2013) concluded prenatal stress was significantly reduced by pyramid exposure and assert pyramids can be used as non-invasive methods of stress management. Plasma cortisol levels were significantly lower ($p < .001$) and basal dendritic intersections were less numerous ($p < .01$) than control groups.

Kamath, Rao, Murthy, Bairy, and S.B. (2006) determined a pyramid environment facilitates the process of wound healing and decreased the suppressant effects of dexamethasone. The pyramid environment showed decreased epithelization period, and a significantly higher rate ($p < .001$) of wound contraction was observed in dexamethasone treated pyramid groups as opposed to those not exposed to a pyramid. Rao (1997) and Kamath (2011) observed pyramids significantly increase breaking strength of skin wounds ($p < .05$) and reduced the anti-healing effects of steroids. Nayak, Rao, Murthy, Somayaji, and Bairy (2003) concluded a pyramid environment promotes better wound healing but cannot completely reverse the suppressant effects of dexamethasone.

Effects of pyramids on liquids

Kumar, Swamy, and Nagendra (2005) tested different shapes of plywood and fiberglass pyramids on milk samples. Kumar et al. (2005) observed all pyramid shapes and materials exhibited lower growth of bacteria than controls, while they assert fiberglass was more effective than wood. Gopinath, Nagarja, and Nagendra (2007) experimented with several materials and sizes of pyramids on bacterial growth in milk. The difference of total bacterial counts between control and wooden pyramids were all significant ($p < .05$), and samples in the pyramids saw a 24-hour delay in deterioration compared to controls. Controls curdled on day two and pyramids curdled by day six.

Narimanov (2000) measured changes in water kept under a pyramid. He observed pH of the sample decreased on day one and then remained constant, and frozen pyramid ice melted faster than control ice. Hydrogen peroxide stored in a pyramid decomposed three times faster than the control. Seeing these results, Abdelsamie, Rahman, and Mustafa (2014) are planning a study using pyramid-shaped packaging for milk and distilled water to determine if this technique could be halal-compliant, meaning food meets the highest quality and safety standards available.

The Great Pyramid of Giza

Because the basis of this research is in regard to pyramids, it may be helpful to review some brief information about the Great Pyramid. The Great Pyramid of Giza is the only remaining wonder from the original Seven Wonders of the World (DeSalvo, 2003; Schul & Pettit, 1975). For centuries, the pyramids in Egypt have been a topic of great interest and discussion among those in scholarly fields. The pyramids of Egypt are located a few miles outside of Cairo on the Giza Plateau (Garnett, 1964; Schul & Pettit, 1975), and these famous structures are said to be named after the Egyptian rulers who commissioned their building (Cleator, 1976). Khufu reigned over Egypt for more than sixty years (Hammerton, 1937). The pyramid of Khufu (known throughout the world as the Great Pyramid of Egypt), is the largest known pyramid in the world today (Schul & Pettit, 1975). Towering between 480 feet and 481 feet tall, the Great Pyramid covers thirteen acres of land (Ceram, 1969; Flanagan, 1973; Forde-Johnston, 1974; Garnett, 1964; Hammerton, 1937).

One of the biggest questions about the Great Pyramid is how a civilization with little technical or mechanical knowledge could build this immense structure to an accuracy of less than a sixteenth of an inch (Cleator, 1976) There are numerous theories regarding how the pyramids were built, and this continues to be a topic of discussion nearly 4,500 years after their building. Most commonly, it is believed a combination of levers, pulleys, ramps and manpower were used to lift and pull stones to their positions (Garnett, 1964). Forde-Johnston (1974) estimates 2,300,000 blocks of stone were used in constructing the Great Pyramid, weighing between two and fifteen tons each. According to Garnett (1964) no account of mechanical labor aids have been discovered. While we now have modern tools to aid in construction, pyramids used for influencing plant growth need to be built as accurate replicas of the Great Pyramid of Giza.

Constructing and Using a Pyramid

According to Brown (1978), the positive effects resulting from pyramids are due to magnetic energy. This can be equated with the similar results seen when a rusty nail is kept in a houseplant or when crops are planted near an iron fence. Thus for a pyramid to produce maximum positive results, it must be aligned with the faces pointing towards magnetic north, south, east, and west. This means having a side facing toward each cardinal direction (Brown, 1978; Davidson, 1997; Flanagan, 1973; Schul & Pettit, 1975, Toth & Nielson, 1974). The Great Pyramid of Giza is aligned to true north with an error of less than one degree, or less than one hundredth of an inch. It is thought true north will produce positive effects to some degree as well, but today magnetic north is optimal. This thought is derived from the belief a pole shift happened after the Great Pyramid was built (Flanagan, 1973; Schul & Pettit, 1975; Toth & Nielson, 1974). Bhat, Rao, Murthy, and Bhat (2007b) compared north-south alignment with random alignment and concluded erythrocyte levels produced by high stress were significantly higher in the random alignment groups, and less stress was present with north/south alignment. This indicates alignment is important for obtaining positive results when using pyramids.

According to Brown (1978) and Davidson (1997), all shapes have the ability to harness magnetic energy, but pyramids are the most efficient due to their geometry. Nahed et al. (2010) provide that energy presence within a pyramid is due to alignment with the earth's magnetic field in combination with the 51° side angles. The Great Pyramid of Giza contains the mathematical irrational numbers of pi ($\pi = 3.14$) and phi ($\Phi = 1.618$) which are thought to be essential to the shapes' interaction with magnetic fields. One-half the base of the pyramid divided into the apothem should result in phi. Pi is 4/square root of phi and is also known as the golden section (Davidson, 1997; Flanagan, 1973; Schul & Pettit, 1975; Toth & Nielson,1974). Phi can also be written as the Fibonacci sequence, which is commonly observed in nature in leaf phylotaxis, pinecones, pineapples, and shells. This may account for the positive effects seen on plants (Flanagan, 1973). A pyramid does not need to be a solid shape; an outline is enough to produce optimal results (Brown, 1978; Davidson, 1997). Additional information about pi and phi can be viewed in Appendix A.

An easy way to calculate the measurements needed to construct a pyramid is to use the base angle to calculate the remaining measurements. The base angle of the Great Pyramid is between 51° and 52° (Flanagan, 1973; Schul & Pettit, 1975; Toth & Nielson, 1974). An online square pyramid calculator can be used to configure the specifications, or Brown (1978), Flanagan (1973), and Toth and Nielson (1974) provide several easy ways to do this by hand, as well as provide pre-calculated dimensions for smaller pyramids. In Figure 1 below, *a* is the base length, *e* is the edge length, and *s* is the slant height. These are the main dimensions used when constructing a pyramid. The base angle referenced above (51.5°) is the angle where *s* meets *a*.

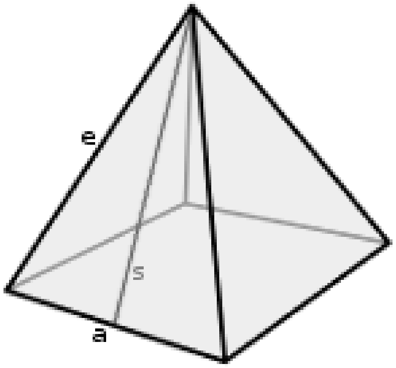

Figure 1. Measurements used to construct a pyramid

Although Brown (1978) ascertains all materials used in pyramid building will effectively collect magnetic energy, others have had different experiences. Flanagan (1973) experimented with different materials including cardboard, wood, plaster, Plexiglas, steel, copper, aluminum, cement, and combinations thereof, but concluded size and orientation of the pyramid had more effect on results than the material. Contradicting Flanagan (1973), Toth and Nielson (1974) assert material is very important for obtaining results, and note construction materials should be homogenous throughout (i.e. compressed cardboard, not corrugated). In yet another experiment, Van Doorne (2013) determined copper pyramids seem to be better than wood in crop trials because copper is more effective at harnessing the magnetic and electromagnetic waves directly from the earth. Davidson (1997) concurs and writes that a copper pyramid is more powerful than a pyramid made from dielectric materials because it deflects and focuses the energy, and non-conductive materials such as plastic will absorb the energy. This provides a basis for Brown's (1978) assertion that pyramids should be grounded with the earth. A scientific article by Kumar et al. (2010) compared wooden and plywood pyramids, and concluded a wooden pyramid was more effective at increasing plant growth. It has also been shown that fiberglass pyramids are more effective than wooden pyramids at inhibiting microbial growth in milk (Gopinath et al., 2007; Kumar et al., 2005).

In addition to the material, the location inside the space of the pyramid is not equally saturated with energy. Nahed et al. (2010) assert there are active and passive zones of energy around pyramids. Bovis claimed energy was most concentrated in the Kings Chamber of the Great Pyramid, which is at one third height from the base in the center of the shape. Flanagan (1973) tested this claim and concluded the energy was present throughout the shape, but indeed it was most concentrated in the center at the one third height level. Schul and Pettit (1975), however, affirm plants closest to the apex have a higher germination rate than other locations.

Yet more factors have been shown to influence the effects received from pyramids. According to Toth and Nielson (1974), the environment around the pyramid should be somewhat constant in temperature and humidity as fluctuations will change the effects. This was tested by Bhat, Rao, Murthy, and Bhat (2010), who concluded stress indicators in rats were significantly lower in pyramids than the control in both hot and cool tests, but differences between the hot season were not significant between control and pyramid groups. Bhat, Rao, Murthy, and Bhat (2014) tested the length of time spent under a pyramid and the effect it had on stress levels in rats. Conclusions indicated there was no significant difference between 2 and 4-week exposure in a pyramid, while stress levels in both groups had lower oxidative stress and plasma cortisol levels than controls. A combination of shape, size and material has also been studied. Kumar and Nagendra (2011) compared square and octagonal pyramids, and results showed fenugreek emergence, radicle growth, and average temperature were all higher in the square pyramid.

Although literature above indicates pyramids can exhibit positive influences on plants, health, and liquids, the cause has yet to be examined scientifically. Hypotheses in literature cite the cause of these positive results as due to the pyramidal shapes' ability to harness magnetic energy. This is a relatively new idea and is difficult to evaluate with modern technology. However, experiments evaluating the direct influence of magnetic and electromagnetic fields on plants, crops, water, and soil have been conducted. Most if not all yielded many of the same results as those reported when using pyramids. The literature below indicates this hypothesis about pyramids is not an unwarranted claim.

Physical Methods of Increasing Plant Growth

Introduction

Treatment methods of plants consist of chemical and physical factors. Chemical techniques are pesticides, herbicides, and fertilizers, in addition to chemicals used for pre-treatment of seeds. Physical factors include magnetic fields, electromagnetic fields, electric fields, ultraviolet radiation, light radiation, heat, lasers, microwave radiation, ultrasound, and ionized radiation (Aladjadjiyan, 2012; Rajasekhar et al., 2011). Physical techniques are primarily used as alternative substitutes to replace chemicals. Rajasekhar et al. (2011) assert one of the main advantage of using physical factors is the absence of pesticide residue in crops and produce. When used in place of chemicals, physical factors are cheaper and help avert soil degradation and water pollution. Magnetic fields are the most popular physical factor used to influence plant germination, growth, yield, and health (Aladjadjiyan, 2012). Magnetic fields have been shown to have numerous positive effects on plant growth and germination characteristics, as well as cause structural changes in water and soil. Electromagnetic fields are a combination of magnetic and electric forces and have also shown positive effects in plants (Patenova, Ginchev, Pavlov, & Sirakov, 2009). A lesser known and implemented technique used to affect plant growth is para magnetic (or low intensity) force. Volcanic rock is the most prevalent technique used and has shown positive effects on soil and plants (Callahan, 1995). It is hypothesized that pyramids use the magnetic field of the earth to generate a para magnetic field within their structure similar to the way volcanic and para magnetic rocks work with the magnetic field of the earth (Brown, 1978; Van Doorne, 2013). Some also suggest pyramids may combine both magnetic and electric forces resulting in a pyramid-induced electromagnetic field (Toth & Nielson, 1974). Davidson (1997) was able to detect a magnetic field with a fiberglass pyramid (310 gammas) but not a paper pyramid. There are 20,000-50,000 gammas in the earth's magnetic field, or as Flanagan (1973) notes, about 0.5 Gauss. Abdelsamie, Rahman, Mustafa, and Hashim (2014) conducted an experiment on inducing magnetic and electric currents in different containers and found the pyramid-shaped container induced the highest levels of electric field in stored water when compared to other shapes.

Magnetism

In magnetism, there are ferromagnetic, para magnetic, and diamagnetic materials. When introduced to a magnetic field, ferromagnetic and para magnetic materials have the ability to rearrange their electron spin resulting in the material becoming magnetized. Para magnetic materials are capable of sustaining their magnetic field once they are removed from the initial field that caused the electron realignment. Ferromagnetic substances are not capable of maintaining their magnetic field once they are removed from the field. Further, para magnetic materials are attracted to the magnetic field while diamagnetic materials are repelled by the field. As opposed to ferro- and para magnetic materials, diamagnetic materials' electron spin is not influenced by magnetic fields (Zuniga et al., 2016).

The factors influencing the use of magnetic fields are the field strength (high, medium, or low; measured in Tesla's or Hertz), character of the field (static or alternating), and the length of exposure time (Aladjadjiyan, 2012; Ali, Samaneh, & Kavakebian, 2014; Najafi, Heidari, & Jamei, 2013; Odhiambo et al., 2009; Rajasekhar et al., 2011). In addition, results seen from inducing a magnetic field depend upon the species and variety of the plant as well as the exposure phase (pre or post germination) and age of the plant (Aladjadjiyan & Ylieva, 2003; Jinapang, Prakob, Wongwattananard, Islam, & Kirawanich, 2010; Pang & Deng, 2008). As was seen in pyramids, Bhatnagar and Deb (1977) also note environmental conditions such as temperature and humidity are important factors affecting the implementation of magnetism techniques.

Odhiambo et al. (2009) concluded North Pole magnetic fields inhibited seed germination while the South Pole induced faster germination. Germination percentage was 73% in South Pole treatment versus 52% in the control. Odhiambo et al. also found seed germination was optimal at an exposure time of 4.5 hours, and both 3 and 6 hours inhibited seed germination, and a level of 10 miliTesla achieved the highest seed germination percentage. Huang and Wang (2008) assert 20 and 60 Hertz magnetic fields enhanced germination of mung beans, while 30, 40, and 50 Hertz fields inhibit germination. 10 Hertz magnetic field had no effect on germination. Podlesny, Pietruszewski, and Podlesna (2004) also received better results from lower frequency fields. Hirano, Ohta, and Abe (1998) assert a strong field inhibited growth and photosynthesis while a low field had a positive effect. Phirke, Kudbe, and Umbarkar (1996) assert magnetic field strength to be more important than increasing exposure time.

Magnetic treatment of plants and seeds

Magnetic fields have been confirmed to affect plant growth and metabolism (Celik, Buyukuslu, Atak, & Rzakoulieva, 2009; Galland & Pazur, 2005; Racuciu, 2011; Shine, Guruprasad, & Anand, 2011). It has been suggested that magnetic treatment also activates enzyme activity and protein formation, cell reproduction, photochemical activity, respiration rate, and nucleic acid content (Aksyonov, Bulychev, Grunina, Goryachev, & Turovetsky, 2000; Atak, Celik, Olgun, Alikamanoglu, & Rzakoulieva, 2007; Celik et al., 2009; Lebedev, Baranskii, Litvinenko, & Shiyan, 1975, Levin & Ernst, 1997; Phirke et al., 1996b; Racuciu, Creanga, & Horga, 2008; Stange, Rowland, Rapley, & Podd, 2002; Wadas, 1992). Labes (1993) discovered magnetic fields influence the cell membranes, increasing ion transport and affecting metabolic pathways.

Exposure of *Phaseolus vulgaris* L. to a static magnetic field increased germination rate (Odhiambo et al., 2009). Influence of an external magnetic field can accelerate emergence by 2-3 days compared to the control, and increase germination percentage and uniformity (Amaya, Carbonell, Martinez, & Raya, 1996; Podlesny et al., 2004). Magnetic treatment increases plant development (Florez, Carbonell, & Martinez, 2007; Gouda & Amer, 2009), and Patenova et al. (2009) confirmed pre-sowing electromagnetic treatment increased the number of sprouts. Positive effects on germination, seedling growth, fruit yield per plant and average fruit weight have been observed (Carbonell et al., 2008; De Souza et al., 2006; Martinez et al., 2009; Odhiambo et al., 2009). Cakmak, Dumlupinar, and Erdal (2010) observed increased germination percentage and growth rate when magnetic fields were applied via field application to beans and wheat. Podlesny, Pietruszewski, and Podlesna (2005) concluded a magnetic field increased emergence, growth, development, and final seed yield in peas, while De Souza et al. (2006) found magnetic fields to improve growth and yield of tomatoes.

Pre-sowing treatment increased seed yield and number of pods per plant (Podlesny et al., 2004), and magnetic treatment has induced germination in a wide variety of plants including barley (Martinez, Carbonell, & Amaya, 2000), tomato (Moon & Chung, 2000), lettuce (Reina, Pascual, & Fundora, 2001), wheat, soybeans, cotton (Phirke, Patil, Umbarkar, & Dudhe, 1996), oak (Celestino, Picazo, & Toribio, 2000), chickpeas (Vashisth & Nagarajan, 2008), rice (Carbonell, Martinez, & Amaya, 2009), beans (Podlesny et al., 2003), mung beans (Jinapang et al., 2010), and corn (Florez et al., 2007). Magnetic treatment of wheat has also been shown to increase gluten and starch in addition to yields (Bhatnagar & Deb, 1977; Frydemberg & Nielson, 1965).

Interestingly, Fu (2012) observed seeds exposed to a magnetic field grew taller than control plants, but when the magnetic field was removed a portion of the stem was weakened and became curved. Fu hypothesized that magnetism provides the plants with energy and helps with survival, and thus the plant experiences negative side effects when the magnetic field is removed.

Magnetic treatment of water

Many researchers believe magnetized water can promote germination and early growth (Qui et al., 2011). Studies indicate magnetic treatment of water influences the molecular and physiochemical properties particularly by altering the water nucleus (Cai, Yang, He, & Zhu, 2009; Coey & Cass, 2000; Gehr, Zhai, Finch, & Rao, 1995; Hasson & Bramson, 1985). Ali et al. (2014) assert magnetic treatment of water restructures the clustering of water molecules into smaller and more uniform hexagonal structures, making the water more adapted to easily enter cell membranes of plants and animals.

Magnetically influenced water is more solvent and has lower surface tension, which amounts to greater absorption of nutrients by the plant (Esitken & Turan, 2004;

Grewal & Masheshwari, 2011; Mohamed & Ebead, 2013b; Moon & Chung, 2000). This is supported by Hajer, Malibari, Al-Zahrani, and Almaghrabi (2006) and Mohamed and Ebead (2013a) who observed irrigation with magnetically treated water increased nutrient mobility in the soil, and significantly increased shoot N, P, and K content in faba beans. Moreover, magnetically treated water has shown positive effects on soil including removal of excess soluble salts and lowering pH values, dissolving phosphates, carbonates, and sulfates, and soluble cations and anions were significantly decreased after applying magnetized water (Esitken & Turan, 2004; Mohamed & Ebead, 2013a).

Moussa (2011) found that use of magnetized water for irrigation of common bean plants significantly increased growth characteristics, potassium, GA3, kinetin, nucleic acids, photosynthetic pigments and activity, and stimulation of antioxidant enzymes resulting in improved quantity and quality of crops. Moussa hypothesizes magnetically treated water could stimulate the plants defense system as well. Magnetically treated water was shown to improve efficiency of water consumption, crop yield, and plant growth (Aghamir, Bahrami, Malakouti, Eshghi, & Sharifi, 2016; Hozayn & Qados, 2010). Maheshwari and Grewal (2009) concluded effects of magnetically treated water vary with plant type, similarly to direct plant or seed treatment with magnetic fields.

In an experiment studying the effects of magnetically treated water on *Phaseolus vulgaris*, Aghamir et al. (2016) hypothesized the significant impacts on growth and development could be caused by increased root and shoot growth. Aghamir et al. also found beans treated with magnetized water to be more resistant to excess soil salinity. Zuniga et al. (2016) suggests use of magnetic fields on water (magneto priming) is only useful if seeds are of low quality.

Para magnetism

Para magnetism is a low-level energy force which is beneficial for all life forms (Beck, 2005). Para magnetic rock exhibits a weak magnetic energy field in response to the Earth's magnetic field (Diver, n.d.). According to Diver (n.d.), Para magnetism was 'rediscovered' in modern times by Dr. Philip Callahan who created the Para magnetic Count Soil Meter (PCSM). This meter measures para magnetic levels in centimeter-grams-seconds (CGS), which is essentially the weight of the para magnetic material that will move toward a magnet the distance of one centimeter in one second. Callahan (1995) provided the range of para magnetic values for soil seen in Table 1 below.

Table 1

Para magnetic values of soil measured in CGS

Soil condition	Value
Poor	0 – 100
Good	100 – 300
Very Good	300 – 700
Superior	> 700

Callahan (1995) asserts volcanoes are blessings in disguise, as rich volcanic soils bring abundance in forests and surrounding cropland after an eruption. According to Beck (2005), Callahan uses volcanite to introduce para magnetism to the soil of crops and plants. Volcanite is a mixture of zeolite rock, sand, and greensand (to balance the minerals) and measures highly on the scale mentioned above, reading 2000+ CGS (Callahan, 1995). According to Van Straaten (2002), zeolites are naturally occurring alumino-silicates with high adsorption, hydration, dehydration and cation-exchange capabilities. Zeolites are extremely efficient ion exchangers as the porosity in their crystal structure provides plentiful space for adsorption and exchange of cations (Van Straaten, 2002; Mumpton, 1984).

Healthy plants will only grow on para magnetic soils (Callahan, 1995). Dumitru, Zdrilic, and Azzopardi (1999) agree with Callahan and concluded rock dust with higher para magnetic intensity is the most beneficial for improving soil quality and plant growth. Soil remineralization by adding nutrients or rock dust does not necessarily mean para magnetic force has been added; the materials should be tested with a PCSM to determine the level of para magnetism. A complex rock dust mixture will be useless for improving soil fertility if a low para magnetic value is present (Callahan, 1995). When used as a compliment to humus-building practices and compost, para magnetic rock dust will provide optimum soil and plant health and help control insects (Callahan, 1995).

Para magnetism and rock dust are closely related. Rock dust is commonly used for soil remineralization in organic agriculture (Diver, n.d.), however when materials with high CGS values are used the added benefit of para magnetic energy will also be present. Rock dust typically refers to finely ground granite and other rocks, but Diver (n.d.) asserts rock dusts of volcanic origin are the most effective. In history all soil was para magnetic, but 60-70% has been depleted over time (Callahan, 1995). Ramos et al. (2015) concluded volcanic rock dust can be used as an alternative fertilizer and is an effective source of micro- and macro- nutrients. Dumitru et al. (1999) note rock dust improves soil pH, water retention, microbial activity, and contains a large range of trace elements.

In Brazil, Theodoro and Leonardos (2006) introduced stonemeal (natural rock powder) to small-scale farmers as a replacement for synthetic fertilizers. The stonemeal substantially increased soil pH and soil contents of Ca+Mg, P, and increased productivity and yield to levels which matched nearby areas treated with chemicals. Additionally, roots of treated plants were more developed, plants displayed exuberant green leaves, and plants retained more moisture. The conclusion was combinations of organic compost and rock fertilizers are adequate at fulfilling most if not all nutrient requirements and are much cheaper in comparison to chemicals due to their long term effects.

Beck (2005) experimented with volcanite and observed tomatoes treated with the rock survived a frost when all other plants died. In another experiment with three plants planted in a row, the two outside plants became infested with aphids while the middle plant (which had been treated with volcanite) remained free of aphids (Beck, 2005). Van Doorne (2013) asserts treating stones in a pyramid will infuse para magnetic potential and have the same effect as volcanic rock dust when spread in a field. Para magnetic basalt can be used in the same way and the results seen in the crop will be even more dramatic (Van Doorne, 2013).

Seed Physiology

The classification of field beans is *Fabaceae* (family), *Phaseolus* (genus), *vulgaris* (species) (USDA, 2017). Commonly known as legumes, this family includes beans, peas, soybeans, alfalfa, and clover (Elias, Copeland, McDonald, & Baalbaki, 2012). Legumes are classified as dicotyledonous angiosperms, differing from gymnosperms in the fact that their seeds are enclosed within an ovary (Elias et al., 2012). Legumes are a simple dry fruit as they are derived from a single pistil and exhibit the characteristic drying of the pericarp at maturity (Elias et al., 2012). Legumes are also dehiscent fruits (as opposed to indehiscent) and split open at maturity to release their seeds (Elias et al., 2012). Field and garden beans exhibit epigeal germination where the cotyledons are raised above the surface for protection (Elias et al., 2012).

A seed contains three plant tissues including a seed coat and embryo as well as nutritive endosperm which serves to feed the seed as it develops and germinates (Washa, 2014). Martin (1946) (as cited in Elias et al., 2012) classified embryos into three types based on their location within the seed, including basal, peripheral, and axial. Legumes are none of the above and are in fact classified as an entire embryo where the embryo fills the entire seed (Elias et al., 2012). An embryo is comprised of the root, shoot and cotyledons. In beans and peas, the endosperm serves primarily for storage (Deno, 1993). Cotyledons are used for photosynthesis in beans after emergence. A seed is a tiny plant that has been packed for transport and storage, and certain conditions must be met for germination to occur (Elias et al., 2012). Germination is the resumption of growth of a dormant embryo, which then will grow into a seedling (Elias et al., 2012). The terms germination and growth are commonly used interchangeably, however as Ranal and Santana (2006) point out, seedling development begins only after germination is complete. Germination begins with seed imbibition (water uptake), followed by enzyme-activated digestion which triggers growth of the embryo and radicle (Washa, 2014). The germination process of beans can be seen below in Figure 2.

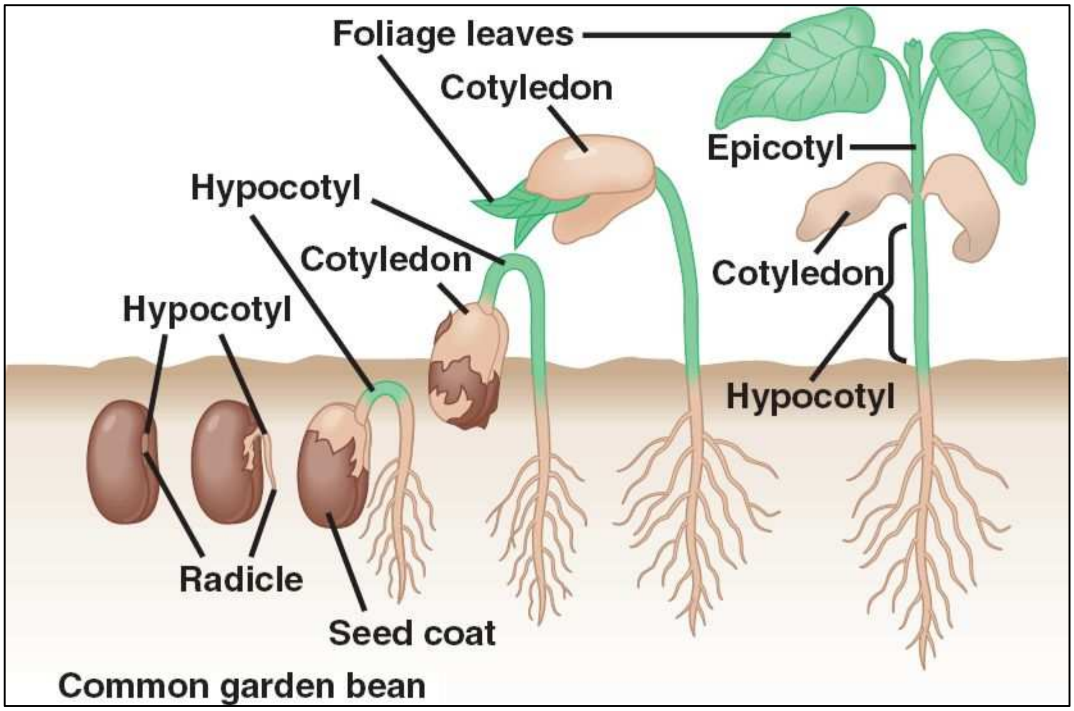

Figure 2. Germination and growth process of beans

(retrieved from www.seedfreedom.net/botany.html)

Factors required for germination are water, temperature, oxygen, and sometimes light (Elias et al., 2012; Washa, 2014). Seeds must also be physiologically mature (Elias et al., 2012), and Sanhewe and Ellis (1996) concluded freshly harvested seeds of beans were only capable of germinating after full maturation, being dried to an adequate desiccation level. The protective seed coat layer regulates water and oxygen levels during germination, but an impermeable seed coat can inhibit germination (Elias et al., 2012). Several pre-sowing methods are prescribed for overcoming impermeability, primarily seed priming. Nezhad, Mirzaei, Shoorkaei, and Shahmiri (2013) note priming as one of the most important methods of increasing seed germination. Ghassemi-Golezani, Chadordooz-Jeddi, Nasrollahzadeh, and Moghaddam (2010) concluded hydro priming of beans for 7 to 14 hours can successfully enhance germination, while Orphanos and Heydecker (1968) assert *Phaseolus vulgaris* seeds often show signs of injury after being submersed in water for more than a few hours. In addition, germination is heavily effected by temperature. Neto, Prioli, Gatti, and Cardoso (2006) affirm seeds exhibit a germination pattern in response to temperature, where germination increases as temperatures rise from the minimum temperature to the optimum temperature. Germination then decreases and ceases as temperature moves from the optimum to the maximum temperature.

Seed testing serves to evaluate seed quality and determine their viability for planting. Seed testing is regulated by the ISTA and AOSA, and rules have been established to ensure congruent methods are used. This ensures comparison among seed laboratories and researchers (Elias et al., 2012; Roos & Wianer, 1991). High quality seed is the basis for productive and profitable agriculture (Roos & Wianer, 1991). Types of seed testing include germination testing, viability testing, physical purity testing, seed vigor assessments, seed health assessments, genetic testing, seed moisture content tests, and seedling evaluation tests (Elias et al., 2012). Most importantly, germination testing provides an indication of how a seed group will perform in the field (Elias et al., 2012).

CHAPTER III

MATERIALS AND METHODS

Research Design

Research was conducted indoors at a laboratory inside Tarleton's Southwest Regional Dairy Center located at 2929 N. U.S. Hwy 281 in Stephenville, Texas (32.256690, -98.196042). Bush bean 'pinto' seeds (*Phaseolus vulgaris*) were purchased from My Patriot Supply online. The beans were guaranteed a 95% germination rate and came in individually wrapped, double-sealed, 1-ounce packages to ensure viability and freshness. Seeds were counted out into groups of 50, randomly placed in pre-labeled 2-ounce polystyrene soufflé cups, weighed, covered with lids, and placed under the corresponding location, either a pyramid or control. Seeds were incubated for four lengths of time: 5, 10, 35, and 45 days. For each time period, three replications each of wooden, copper, and control were tested. Seed groups consisted of 50 seeds i.e. 150 wooden, 150 copper, 150 control for each time period, thus meeting AOSA (1970) regulations of testing at least 400 seeds during a germination test. A total of $N = 1,800$ seeds were tested.

Once the seeds had been incubated for the specified length of time, seeds were removed from the pyramids, weighed, rolled into groups of 25 on moistened germination paper, placed in pre-labeled quart-sized polyethylene bags, sealed, and placed inside the germination chamber. Because groups consisted of 50 seeds, two rolls were placed in each bag. Germination paper used was Anchor regular weight 38-pound 10"x15" crepe paper. The paper was folded in half and trimmed one inch (resulting in 10"x13") to fit inside the quart bags. Distilled water was used to dampen the substrate. Initial wetting was guided by wetting the paper until it was thoroughly soaked, but to where when the paper was picked up by two corners water was not dripping off. As recommended by the Texas Department of Agriculture (TDA) State Seed Lab in Giddings, Texas, the internal environment of the germination chamber was set for a 16-hour/8-hour diurnal photoperiod of night and day at 20°C and 30°C respectively. Relative humidity was set at 95%, however the chamber was only able to maintain 84.8 ± 2%. The night cycle was set for 17:00 to 9:00 hours and the day cycle set for 9:00 to 17:00 hours. The setting was non-ramping, so at 9:00 and 17:00 the chamber automatically switched the lights on or off and adjusted the temperature immediately. The environment chamber used in the study was a customized Percival Model DR36VLC8 constructed with two pre-programmed light settings and a pan-type humidifier. Manufacturer information can be seen in Appendix B.

The germination test was performed for seven days after putting the seeds in the germination chamber, or eight days total, upon recommendation by the TDA State Seed Lab in Giddings, Texas. A complete schedule of activities can be seen in Appendix C. The seeds were checked daily for moisture, moistened if needed, and the number of germinated seeds was counted and recorded. The need for watering was assessed by the color of the germination paper. The paper was light brown when dry, and turned dark brown as it absorbed water. When the paper was an even dark brown color, no more water was added. Care was taken to ensure samples were checked daily at the same time in order to receive accurate germination counts. The official germination parameter was radicle length at or exceeding 2 mm (Mena et al., 2015; Rigon, Capuani, Cherubin, Wastowski, & Da Rosa, 2012). Seeds were handled as little as possible during the experiment, and a long-neck eye dropper bottle was used to control dampening of the substrate. Filter paper was placed in the bags to reduce moisture if seeds showed preliminary signs of molding or if overwatering occurred. If mold or fungi was extensive, seeds were removed and the situation (germinated or non-germinated) was noted.

Filter paper was used to segregate seeds within the substrate if they exhibited initial signs of molding or bacteria growth. Seeds were removed when they became covered with mold. Notes were made to indicate if the seed had germinated and what the cause of removal was. Moldy seeds were removed in an effort to keep mold and bacteria from spreading to other seedlings. Information about the number of moldy seeds can be seen in Appendix D. After the 8-day germination period, seeds were left in the germination chamber for an additional five days to allow for seedling growth. Seedlings were checked daily for moisture and moistened if needed. Again, if mold or bacteria were present seedlings were recorded and removed. On day five of the growth period, fresh weight was taken and seedlings were put into an oven at 105°C +/- 2° for 48 hours. Medium-sized aluminum loaf pans were used to separate groups during drying. The oven model was a VWR 1370F. After drying, seedling dry weight was recorded immediately.

In addition to the seed data collected, soil conditions inside the pyramid were monitored. A Luster Leaf Rapitest Digital 3-way Analyzer (No. 1835) was used to record pH and temperature of the soil for $n = 29$ days. A Flir TG 165 Digital Imaging IR Thermometer was used to record thermal images of the pyramids, taken in an effort to view any changes in temperature present inside the pyramid. Thermal images of the pyramids can be viewed in Appendix E.

Pyramid Construction

Two pyramid shapes were constructed with the following dimensions: 26” height, 41.35” base length, 33.2” slant height, base angle of 51.5°, and apex angle of 38.5°. The after-building measurements of the pyramids are seen below in Table 2; the disparity is due to human error. The research plan originally called for larger pyramids, but smaller pyramids were built to fit through the laboratory door.

Table 2

Pyramid specifications

Material	Height	Base length	Slant height
Wooden	26”	41.2”	33.2”
Copper	25.2”	41.4”	33”

Wooden 2x4s and 1/2” copper tubing was used in building each respectively. Pyramids were constructed with a base angle measurement of 51.5°. The wooden pyramid was constructed using a table saw and nails. Four copper 90° fittings were used to build the copper pyramid base, the top and bottom ends of the four slants were crimped using a vise and soldiered together, and the bottom ends were screwed to the base, completing the copper pyramid. Images of the completed pyramids can be seen below in Figures 3 and 4.

Figure 3. Wooden pyramid

Figure 4. Copper pyramid

Pyramid Set Up

Pyramids were set up on a lab table made of non-conductive material, and a Military Prismatic Compass was used to align the pyramids to magnetic north. Magnetic declination was calculated as 4° 15.96’ East on July 10, 2016 using the coordinates mentioned in the section on research design above (Natural Resources Canada, 2017). This means the magnetic field of the Earth at these coordinates varies by a little more than four degrees from magnetic north. Pyramids were located about eight feet from each other to ensure they would not influence one another during the experiment. According to Flanagan (1973), energy radiates from the points of the pyramid, and if the control is placed too near a pyramid it will be affected also. Six quart containers and potting soil were used as a platform within the pyramid to establish the one-third height level necessary for incubating the seeds. Using the after-building dimensions, the one third height level was measured at 8.5”. A picture of the set up can be seen below in Figure 5.

Figure 5. Pyramid one third height and alignment to magnetic north

Mathematical Equations

Germination percentage

The term germination is often used interchangeably with seedling growth (Ranal & Santana, 2006) causing confusion in seed evaluation and use of formulas. For this research, the definition of germination was the radicle length at or exceeding 2 mm in length (Mena et al., 2015; Rigon et al., 2012). Germination percentage was calculated for each of the samples at the conclusion of the eight-day germination test. The formula below (see Figure 6) shows the calculation of this percentage, where n_i is the total number of seeds germinated at time i, and n is the total number of seeds in the test (Aghamir et al., 2016; Ranal, Santana, Ferriera, & Mendes-Rodrigues, 2009). Germination percentage measures the percentage of seeds that have reached the end of the germination process (Ranal & Santana, 2006), thus a higher germination percentage is more favorable. Only viable/good seeds will complete the germination process. Formula limits can be seen in Table 3.

$$G = \frac{\sum_{i=1}^{k} n_i}{n} \times 100$$

Figure 6. Germination percentage

Mean germination time

Mean germination time *(MGT)* was calculated according to the formula below (see Figure 7), where $\bar{t}$ is the mean germination time, n_i is the number of seeds germinated at the i^{th} time (not accumulated), and t_i is the time from the start of the experiment to the i^{th} observation (Ranal & Santana, 2006). Mean germination time is the reciprocal of mean germination rate. *MGT* is more reliable than measuring the time for first germination or using the median germination time because it measures the central tendency of the sample, thus accounting for early and late maturing seeds (Ranal & Santana, 2006). A lower mean germination time is more beneficial as this indicates faster seed germination. Formula limits can be seen in Table 3.

$$\bar{t} = \sum_{i=1}^{k} n_i t_i \,/ \sum_{i=1}^{k} n_i$$

Figure 7. Mean germinating time

Coefficient of variation of germination time

Variance of germination time was calculated according to the formula below (see Figure 8) where n_i is the number of seeds germinated at the i^{th} time (not accumulated), t_i is the time from the start of the experiment to the i^{th} observation, and $\bar{t}$ is the *MGT* (Ranal & Santana, 2006).

$$S_t^2 = \frac{\sum_{i=1}^{k} n_i (t_i - \bar{t}\,)^2}{\sum_{i=1}^{k} n_i - 1}$$

Figure 8. Variance of germination time

The coefficient of variation of germination time (CV_t) was then calculated using the S_t^2 values previously obtained. CV_t evaluates germination uniformity and was first proposed by Dorneles et al. and Carvalho et al. (as cited in Ranal & Santana, 2006) as a replacement for coefficient of uniformity of germination. This formula is easier to interpret than the previously used formula and allows for comparisons to be made between samples because it disregards the magnitude of the *MGT* (Ranal & Santana, 2006). In the formula below (Figure 9), S_t is the standard deviation of the *MGT* and $\bar{t}$ is the *MGT*. A smaller coefficient indicates less variation in germination time, while a larger coefficient indicates more variation. Formula limits can be seen in Table 3.

$$CV_t = \frac{S_t}{\bar{t}} \times 100$$

Figure 9. Coefficient of variation of germination time

Mean germination rate

Mean germination rate (*MGR*) is the reciprocal of mean germination time. The formula below (see Figure 10) was presented by Labouriau (as cited in Ranal & Santana, 2006) as a way to calculate *MGR* using the coefficient of velocity of Kotowski. n_i is the number of seeds germinated in the i^{th} time, t_i is the time from the start of the experiment to the i^{th} observation, and k is the last day of the test. A higher germination rate indicates higher germination speed. Formula limits can be seen in Table 3.

$$\bar{v} = \frac{\sum_{i=1}^{k} n_i}{\sum_{i=1}^{k} n_i t_i}$$

Figure 10. Mean germination rate

Uncertainty of the germination process

Uncertainty of the germination process (U) measures the degree of dispersion of germination through time, thus a lower U value indicates germination that is more concentrated and where there are less peaks in frequency of seed germination (Ranal & Santana, 2006). Calculation of the relative frequency of germination is required to calculate U. The formula for relative frequency is seen below in Figure 11, where f_i is relative frequency, n_i is the number of seeds germinated on day i, and k is the last day of the trial.

$$f_i = \frac{n_i}{\sum_{i=1}^{k} n_i}$$

Figure 11. Relative frequency of germination

Using the relative frequency of germination, it is possible to calculate U (see Figure 12 below). Note the negative sign before the summation. Formula limits can be seen in Table 3.

$$U = -\sum_{i=1}^{k} f_i \log_2 f_i$$

Figure 12. Uncertainty of the germination process

Synchrony of germination

Synchrony of germination (Z) measures the degree of overlapping of germination of seeds in the same sample. $c_{n_i,2}$ is the combination of seeds germinated in the i^{th} time, two together, and n_i is the number of seeds germinated at time i. Thus $Z = 1$ when germination occurs at the same time, and $Z = 0$ when at least two seeds germinated, one at each time (Ranal & Santana, 2006). Using $c_{n_i,2}$ (see Figure 13), it is then possible to calculate Z (see Figure 14). A higher synchrony value indicates more uniform germination. Formula limits can be seen in Table 3.

$$c_{n_i,2} = \frac{n_i(n_i - 1)}{2}$$

Figure 13. Combination of seeds germinated

$$Z = \frac{\sum_{i=1}^{k} C_{n_i,2}}{C_{\sum n_i,2}}$$

Figure 14. Synchrony of germination

Tissue water content

Tissue water content *(TWC)* was calculated using the formula below (see Figure 15), where FW is the fresh weight of the sample and DW is the dry weight of the sample (Aghamir et al., 2016). The formula used was developed by Black and Pritchard and uses fresh and dry weight (Aghamir et al, 2016).

$$TWC = FW - DW/FW \times 100$$

Figure 15. Tissue water content

Change in seed weight

Change in seed weight before and after charging (Δ) was calculated according to the formula below (see Figure 16), where wa is the after-incubation weight and wb is the before-incubation weight.

$$\Delta = (wa - wb) \times 100/wb$$

Figure 16. Change in seed weight

Assumptions

Independent variables were pyramid material (wooden, copper, control) and length of incubation period (5, 10, 35, and 45 days). Dependent variables were change in seed weight, germination percentage, mean germination time, coefficient of variation of germination time, mean germination rate, synchrony of germination, uncertainty of germination, soil temperature, and soil pH. Dependent variables were measured at interval or ratio level using a continuous scale. All samples were random samples and observations were independent of one another. The data had slight abnormal distribution and several steps were taken to validate statistical results. According to Pallant (2010) results from sample sizes larger than 30 will not be misreported due to use of statistical measures meant for normally distributed data. There was no missing data. There were minimal outliers present and these only occurred in the soil temperature data. A summary of formula limits and units of measure can be seen in Table 3 below, and a complete list of variables can be viewed in Table 4.

Table 3

Formula limits and units of measure

Measurement	Limits	Unit of Measure
Germination Percentage	$0 \leq G \leq 100$	%
Mean Germination Time	$0 < \bar{t} \leq \mathrm{k}$	day
Coefficient of Variation of Germination Time	$0 < CV_t \leq \infty$	%
Mean Germination Rate	$0 < \bar{v} \leq 1$	day^{-1}
Uncertainty of the Germination Process	$0 \leq U \leq \log_2 \mathrm{n}$	bit
Synchrony of Germination	$0 \leq Z \leq 1$	unit less
Tissue Water Content		%
Change in Seed Weight		%

Statistical Analysis

Microsoft Excel was used to record data in a spreadsheet and calculate the following values: G, MGT, CV_t, MGR, U, Z, TWC and Δ. IBM SPSS Version 23 was then used to analyze results from the above calculations as well as soil data. The data were subjected to multiple one-way analysis of variances (ANOVA) at $p \leq .05$ level of significance, and treatments were compared with the control groups. When evaluating descriptive statistics, Levene's test used to assess equality of variance and normality of the data were assessed via Shapiro-Wilk. Because some data were significant in Levene's test, Welch's F was reported additionally to help validate ANOVA p-values. Eta squared was also calculated to estimate effect size. Sum of squares corrected total was used to calculate effect size as opposed to total sum of squares.

Table 4

List of variables and corresponding abbreviations, descriptions, and coding

Variable	Abbreviation	Description	SPSS Coding
Pyramid Material	W – wooden	Independent	1 - wooden
	C – copper		2 - copper
	X - control		3 - control
Incubation Period	5 – 5 days	Independent	1 – 5 days
	10 – 10 days		2 – 10 days
	35 – 35 days		3 – 35 days
	45 – 45 days		4 – 45 days
Germination Percentage	G	Dependent	
Mean Germination Time	$\bar{t}$	Dependent	MGT
Coefficient of Variation of Germination Time	CV_t	Dependent	
Mean Germination Rate	$\bar{v}$	Dependent	MGR
Uncertainty of the Germination Process	U	Dependent	
Synchrony of Germination	Z	Dependent	
Fresh weight	DW	Dependent	
Dry weight	FW	Dependent	
Tissue Water Content	TWC	Dependent	
Weight before incubation	wb	Dependent	
Weight after incubation	wa	Dependent	
Change in seed weight	Δ	Dependent	
Soil temperature	st	Dependent	
Soil pH	pH	Dependent	

Table 5 below shows the resulting values from Levene's test of equality of error variances. Significant values indicate inequality of data variance, however as noted by Field (2009), large sample sizes have a tendency to indicate false significant values. Mean germination time, mean germination rate, tissue water content, and soil temperature all appear to have equal variance, while germination percentage F(11, 24) = 6.117, $p < .001$; coefficient of variation of germination time F(11, 24) = 2.397, $p < .036$; uncertainty of the germination process F(11, 24) = 2.709, $p < .020$; synchrony of germination F(11, 24) = 2.464, $p < .031$ and change in seed weight F(11, 24) = 4.118, $p < .002$ indicate unequal variance among data scores.

Table 5

Resulting values from Levene's test for equality of error variances

Variable	F	*df*1	*df*2	*p*
G	6.117	11	24	**.001**
MGT	1.526	11	24	.186
CV_t	2.397	11	24	**.036**
MGR	1.375	11	24	.247
U	2.709	11	24	**.020**
Z	2.464	11	24	**.031**
TWC	2.136	11	24	.058
Δ	4.118	11	24	**.002**
st	0.187	2	84	.830

Note. G: germination percentage; MGT: mean germination time; CV_t: coefficient of variation of germination time; MGR: mean germination rate; U: uncertainty of the germination process; Z: synchrony of germination; TWC: tissue water content; Δ: change in seed weight; *st*: soil temperature; F: Levene's test value; *df*: degrees of freedom; *p*: *p*-value; boldface values indicate unequal variance between variables

Table 6 below examines the resulting values from Shapiro-Wilk's test of normality of distribution. Shapiro-Wilk was used rather than Kolmogorov-Smirnov because it has more power to detect differences in normality (Field, 2009). While significant values from this test indicate abnormal data distribution, Field (2009) indicates large sample sizes can be prone to significant results and thus personal judgement should be used when assessing distribution. As seen in Table 6 below, germination percentage ($W = .747$, $p < .001$) and change in seed weight ($W = .849$, $p < .001$) both deviate from normal distribution. All other variables appear to be normally distributed.

Table 6

Resulting values from Shapiro-Wilk's test of normality

Variable	*W*	*df*	*p*
G	.747	36	**.001**
MGT	.954	36	.140
CV_t	.989	36	.967
MGR	.968	36	.384
U	.967	36	.355
Z	.964	36	.294
TWC	.986	36	.918
Δ	.849	36	**.001**

Note. G: germination percentage; MGT: mean germination time; CV_t: coefficient of variation of germination time; MGR: mean germination rate; U: uncertainty of the germination process; Z: synchrony of germination; *TWC*: tissue water content; Δ: change in seed weight; *W*: Shapiro-Wilk value; *df*: degrees of freedom; *p*: *p*-value; values in bold indicate abnormality of distribution

CHAPTER IV

RESULTS

Objective 1 Results

Objective 1 sought to describe the impact of pre-sowing incubation within a pyramid on germination characteristics (G, MGT, CV_t, MGR, U, Z). Independent variables were pyramid material and incubation period, and dependent variables were germination percentage, mean germination time, coefficient of variation of germination time, mean germination rate, uncertainty of the germination process, and synchrony of germination. When examining seed germination, it is useful to examine germination frequency in addition to germination percentage as frequency provides the actual number of germinated seeds. As seen in Table 7 below, the control group (*M* = 49.7), wooden pyramid (*M* = 49.25), and copper pyramid (*M* = 47.9) saw the highest to lowest mean total of germinated seeds respectively. When examined by incubation period, 45 days (*M* = 49.33) saw the highest average frequency followed by periods of 5 days, 35 days, and 10 days.

Table 7

Mean frequency of seed germination of Phaseolus vulgaris seeds incubated within pyramids of varying materials under four incubation periods

	5 days	10 days	35 days	45 days	Total
Wooden	49	49	49	50	49.25
Copper	48.6	47	48.3	48	47.9
Control	49.6	49.6	49.6	50	49.7
Total	49.1	48.5	48.96	49.33	

Note. Mean values are an average of germinated seeds from three replications of 50 seeds each; a total of *N* = 1,800 seeds were germinated

Table 8 below examines descriptive statistics of germination characteristics under varying pyramid materials. The highest germination percentage occurred in the control group (*M* = 99.33, *SD* = 0.98), with the wooden pyramid and copper pyramid following. According to mean germination time, the quickest germination occurred in the control group (*M* = 3.91, *SD* = .09), followed by the wooden and copper pyramids respectively. Coefficient of variation of germination time indicates the copper pyramid saw more uniformity in germination (*M* = 16.92, *SD*=4.81) followed by the control and wooden pyramid. The control group had the highest mean germination rate (*M* = 0.2559, *SD* = .006) followed by the wooden and copper pyramids. The copper pyramid had the lowest uncertainty of germination (*M* = 1.16, *SD* = 0.26) followed by the control and wooden pyramid. The copper pyramid also had the highest germination synchrony (*M* = 0.55, *SD*

= 0.07) followed by the wooden pyramid and control group. Means not sharing subscripts differ by $p < .05$ according to Tukey's HSD Post-Hoc test.

Table 8

Descriptive statistics of germination measurements of Phaseolus vulgaris seeds after incubation under pyramids of varying materials

	Wooden		Copper		Control	
	M	*SD*	*M*	*SD*	*M*	*SD*
G (%)	98.50_b	1.24	96.00_a	3.30	99.33_b	0.98
MGT (day)	3.93_a	0.14	3.96_a	0.18	3.91_a	.09
CV_t (%)	20.01_a	3.03	16.92_a	4.81	17.09_a	3.68
MGR (day^{-1})	0.2549_a	0.009	0.2529_a	0.011	0.2559_a	0.006
U (bit)	1.28_a	0.17	1.16_a	0.26	1.21_a	0.25
Z	0.49_a	0.06	0.55_a	0.07	0.53_a	0.09

Note. $n = 12$; G: germination percentage; MGT: mean germination time; CV_t: coefficient of variation of germination time; MGR: mean germination rate; U: uncertainty of the germination process; Z: synchrony of germination; means that do not share subscripts differ by $p < .05$ according to Tukey's HSD Post-Hoc test for homogeneous subsets

It is also necessary to examine the germination characteristics according to incubation period. Table 9 below examines germination characteristics for varying incubation periods under the pyramids. The highest germination percentage occurred at an incubation period of 45 days (*M* = 98.67, *SD* = 2.65, followed respectively by 5 days, 35 days, and 10 days. Mean germination time was quickest at a period of 35 days (*M* = 3.83, *SD* = 0.08), 45 days (*M* = 3.89, *SD* = 0.10), and 5 days (*M* = 3.97, *SD* = 0.09), and 10 days was the slowest (*M* = 4.04, *SD* = 0.17). The most uniformity in germination time was seen at 35 days (*M* = 15.77, *SD* = 1.23) followed by 45 days, 5 days, and 10 days respectively. The highest mean germination rate occurred at 35 days (*M* = 0.2614, *SD* = .006) followed by 45 days, 5 days, and 10 days. An incubation period of 45 days saw the most concentrated germination (*M* = 1.05, *SD* = 0.23), followed by 35 days, 5 days, and 10 days. The most synchrony in germination was exhibited by an incubation period of 45 days (*M* = 0.58, *SD* = 0.08), 35 days (*M* = 0.55, *SD* = 0.06), 5 days (*M* = 0.51, *SD* = 0.06), and 10 days (*M* = 0.46, *SD* = 0.06). Means not sharing subscripts differ by $p < .05$ according to Tukey's HSD Post-Hoc test. Graphs of *G, MGT,* CV_t*, MGR, U,* and *Z* sorted by pyramid material and incubation period can be seen in Appendix F (Figures 23-28).

Table 9.

Descriptive statistics of germination measurements of Phaseolus vulgaris seeds after varying incubation periods within a pyramid

	5 days		10 days		35 days		45 days	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
G (%)	98.22_{a}	1.20	97.11_{a}	3.76	97.78_{a}	1.86	98.67_{a}	2.65
MGT (day)	3.97_{ab}	0.09	4.04_{b}	0.17	3.83_{a}	0.09	3.89_{ab}	0.10
CV_t (%)	18.20_{ab}	3.75	20.99_{b}	4.23	15.77_{a}	1.23	17.08_{ab}	4.69
MGR (day^{-1})	0.2519_{ab}	0.006	0.2482_{a}	0.010	0.2614_{b}	0.006	0.2568_{ab}	0.007
U (bit)	1.29_{ab}	0.15	1.42_{b}	0.21	1.11_{a}	0.13	1.05_{a}	0.23
Z	0.51_{ab}	0.06	0.46_{a}	0.06	0.55_{ab}	0.06	0.58_{b}	0.08

Note. $n = 9$; G: germination percentage; MGT: mean germination time; CV_t: coefficient of variation of germination time; MGR: mean germination rate; U: uncertainty of the germination process; Z: synchrony of germination; means that do not share subscripts differ by $p < .05$ according to Tukey's HSD Post-Hoc test for homogeneous subsets

Objective 2 Results

Objective 2 sought to describe the impact of pre-sowing incubation within a pyramid regarding seedling growth. Independent variables were pyramid material and incubation period. Dependent variables were fresh weight, dry weight, and tissue water content. As seen in Table 10 below, the highest vegetative growth (lowest *TWC*) was seen in the copper pyramid (*M* = 80.63*, SD* = 1.39), control (*M* = 80.91, *SD* = 1.19), and wooden pyramid (*M* = 80.96, *SD* = 1.37) respectively. As seen in Table 11, the highest amount of vegetative growth occurred at incubation periods of 5 days (*M* = 80.09, *SD* = 0.7), 10 days (*M* = 80.25, *SD* = 1.13), 45 days (*M* = 80.95, *SD* = 1.12), and 35 days (*M* = 82.04, *SD* = 1.21). Means not sharing subscripts differ by $p < .05$ according to Tukey's HSD Post-Hoc test. A graph of *TWC* sorted by pyramid material and incubation period can be seen in Appendix F (Figure 29).

Table 10

Descriptive statistics of seedling growth of Phaseolus vulgaris seeds after incubation within a pyramid under varying pyramid materials

	Wooden		Copper		Control	
	M	*SD*	*M*	*SD*	*M*	*SD*
FW (g)	57.42	4.25	57.69	3.63	57.00	10.85
DW (g)	10.89	0.43	11.14	0.44	3.57	0.45
TWC (%)	80.96_{a}	1.37	80.63_{a}	1.39	80.91_{a}	1.19

Note. *n* = 12; *FW*: fresh weight; *DW*: dry weight; *TWC*: tissue water content; means that do not share subscripts differ by $p < .05$ according to Tukey's HSD Post-Hoc test for homogeneous subsets

Table 11

Descriptive statistics of seedling growth of Phaseolus vulgaris seeds after incubation within a pyramid under varying time periods

	5 days		10 days		35 days		45 days	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
FW (g)	55.49	1.47	54.37	10.72	61.82	3.47	57.81	2.53
DW (g)	11.05	0.61	10.72	0.39	11.07	0.43	10.99	0.28
TWC (%)	80.09_{a}	0.77	80.25_{a}	1.13	82.04_{b}	1.21	80.95_{ab}	1.12

Note. *n* = 9; *FW*: fresh weight; *DW*: dry weight; *TWC*: tissue water content; means that do not share subscripts differ by $p < .05$ according to Tukey's HSD Post-Hoc test for homogeneous subsets

Objective 3 Results

Objective 3 sought to describe the impact of pre-sowing incubation within a pyramid regarding seed weight. Independent variables were pyramid material and incubation period. Dependent variables were weight after charging and change in seed weight. As seen in Table 12 below, the control group had the highest change in seed weight (*M* = 1.069, *SD* = 0.88) with the wooden and copper pyramids following.

Table 12

Descriptive statistics of desiccation of Phaseolus vulgaris seeds after incubation within a pyramid under varying pyramid materials

	Wooden		Copper		Control	
	M	*SD*	*M*	*SD*	*M*	*SD*
wb (g)	15.54	0.46	15.69	0.57	15.63	15.79
wa (g)	15.69	0.48	15.85	0.62	0.58	0.63
Δ (%)	1.015_a	0.91	1.008_a	0.88	1.069_a	0.88

Note. *n* =12; *wb*: weight before incubation; *wa*: weight after incubation; Δ: change in weight; means that do not share subscripts differ by $p < .05$ according to Tukey's HSD Post-Hoc test for homogeneous subsets

As seen in Table 13 below, the highest change in seed weight occurred at a period of 45 days (*M* = 2.147, *SD* = 0.25), followed by 35 days, 10 days, and 5 days. Means not sharing subscripts differ by $p < .05$ according to Tukey's HSD Post-Hoc test. A graph of Δ sorted by pyramid material and incubation period can be seen in Appendix F (Figure 30).

Objective 4 Results

Objective 4 sought to describe the impact of pyramid presence and construction material regarding soil condition. The independent variable was pyramid material and dependent variables were soil temperature and soil pH. The pH of the soil remained

Table 13

Descriptive statistics of desiccation of Phaseolus vulgaris seeds after incubation within a pyramid under varying time periods

	5 days		10 days		35 days		45 days	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
wb (g)	15.64	0.74	15.37	0.39	15.82	0.44	15.65	0.44
wa (g)	15.66	0.74	15.42	0.39	16.07	0.45	15.98	0.44
Δ (%)	0.106_a	0.03	0.332_b	0.11	1.538_c	0.14	2.147_d	0.25

Note. $n = 9$; *wb*: weight before incubation; *wa*: weight after incubation; Δ: change in weight; means that do not share subscripts differ by $p < .05$ according to Tukey's HSD Post-Hoc test for homogeneous subsets

constant at pH 7.0 for all groups regardless of pyramid material, thus this variable was omitted from analysis. As seen in Table 14 below, the wooden pyramid had the highest mean temperature ($M = 70.28$, $SD = 1.601$) followed by the control and the copper pyramid. Means not sharing subscripts differ by $p < .05$ according to Tukey's HSD Post-Hoc test. Bolded Shapiro-Wilk values indicate data abnormality.

Table 14

Descriptive statistics of soil temperature after incubation within a pyramid under varying pyramid materials

	n	*M*	*SD*	SE	Min	Max	Shapiro-Wilk
Wooden	29	70.28_b	1.601	0.297	66	74	**.001**
Copper	29	67.93_a	1.907	0.354	64	73	**.006**
Control	29	69_a	1.909	0.354	65	75	**.016**
Total	87	69.07	2.033	0.218	64	75	

Note. Means that do not share subscripts differ by $p < .05$ according to Tukey's HSD Post-Hoc test for homogeneous subsets; boldface values indicate abnormality according to Shapiro-Wilk's test of abnormality

Results from a one-way ANOVA are seen in Table 15. The analysis revealed a statistically significant effect between groups ($p < .001$). Welch's F also reported significance findings, and eta squared revealed a large effect size ($\eta^2 = .225$). The frequency distribution of soil temperature can be seen in Appendix F (Figure 31).

Table 15

Comparative analysis of soil temperature among varying pyramid materials

	SS	*df*	MS	F	*p*	Welch	η^2
Between groups	79.93	2	39.97	12.18	**.001**	**.001**	.225
Within groups	275.66	84	3.28				
Total	355.59	86					

Note. One-way ANOVA output; SS: sum of squares; *df*: degrees of freedom; MS: mean square; *p*: significance; boldface values indicate significance at $p < .05$; η^2: eta squared

Objective 5 Results

Objective 5 sought to describe any linear relationship existing between pyramid construction material, germination characteristics, seedling growth, and change in seed weight. The independent variable was pyramid material and independent variables were germination percentage, mean germination time, coefficient of variation of germination, mean germination rate, uncertainty of the germination process, synchrony of germination, tissue water content, and change in seed weight. ANOVA results indicate pyramid material had a significant effect on germination percentage (F = 7.386, $p < .005$), and eta squared revealed a large effect size ($\eta^2 = .328$). Material had a statistically insignificant effect on all other variables. Eta squared revealed medium effect sizes for coefficient of variation of germination time ($\eta^2 = .125$) and synchrony of germination ($\eta^2 = .067$).

Table 16

Impact of varying pyramid materials on germination characteristics, seedling growth, and change in seed weight

	SS	*df*	MS	F	*p*	Welch	η^2
G (%)	72.22	2	36.11	7.386	**.003**	**.008**	.328
MGT (day)	.017	2	.008	.620	.546	.664	.025
CV_t (%)	72.257	2	36.128	2.697	.088	.076	.125
MGR (day^{-1})	5.7E-5	2	2.88E-5	.524	.599	.705	.019
U (bit)	.089	2	.045	1.22	.313	.392	.048
Z	.014	2	.007	1.648	.213	.210	.067
TWC (%)	.028	2	.014	.498	.614	.824	.013
Δ (%)	.749	2	.375	.359	.702	.983	.001

Note. G: germination percentage; MGT: mean germination time; CV_t: coefficient of variation of germination time; MGR: mean germination rate; U: uncertainty of the germination process; Z: synchrony of germination; *TWC*: tissue water content; Δ: change in seed weight; SS: sum of squares; *df*: degrees of freedom; MS: mean square; *p*: significance; boldface values indicate significance at $p < .05$; η^2: eta squared

Objective 6 Results

Objective 6 sought to describe any linear relationship existing between length of pre-sowing incubation period, germination characteristics, seedling growth, and change in seed weight. The independent variable was incubation period and dependent variables were germination percentage, mean germination time, coefficient of variation of germination time, mean germination rate, uncertainty of the germination process, synchrony of germination, tissue water content, and change in seed weight. Every variable with the exception of germination percentage saw significant ANOVA results. Welch's F values corroborate *p*-values obtained. Eta squared revealed large effect sizes for every variable except germination percentage, which indicated a small effect size ($\eta^2 = .054$).

Table 17

Length of pre-sowing incubation period impacts on germination characteristics, seedling growth, and change in seed weight

	SS	*df*	MS	F	*p*	Welch	η^2
G (%)	11.889	3	3.963	.811	.5	.733	.054
MGT (day)	.222	3	.074	5.421	**.005**	**.008**	.331
CV_t (%)	133.185	3	44.395	3.314	**.037**	**.017**	.231
MGR (day^{-1})	.001	3	.001	5.458	**.005**	**.009**	.333
U (bit)	.775	3	.258	7.062	**.001**	**.003**	.419
Z	.072	3	.024	5.556	**.005**	**.014**	.346
TWC (%)	21.323	3	7.108	6.809	**.002**	**.007**	.368
Δ (%)	25.604	3	8.535	306.270	**.001**	**.001**	.971

Note. G: germination percentage; MGT: mean germination time; CV_t: coefficient of variation of germination time; MGR: mean germination rate; U: uncertainty of the germination process; Z: synchrony of germination; TWC: tissue water content; Δ: change in seed weight; SS: sum of squares; *df*: degrees of freedom; MS: mean square; *p*: significance; boldface values indicate significance at $p < .05$; η^2: eta squared

CHAPTER V

CONCLUSIONS

Conclusions

Objective 1 conclusions

Objective 1 sought to describe the impact of pre-sowing incubation within a pyramid on germination characteristics (G, MGT, CV_t, MGR, U, Z). With regard to pyramid material (see Table 8), it appears the copper pyramid negatively affected measurements of germination speed (*G, MGT, MGR*) and germination frequency (*f*), in contrast to results obtained by Vasavada and Gadani (2012), Kumar et al. (2010), Kuzmina et al. (2013), and Narimanov (2000). The control groups saw higher germination frequency, germination percentage, and germination rate, and saw decreased germination time when compared to pyramid groups. Contrary to Davidson (1997), the least positive impact (or most negative impact) was exhibited by the copper pyramid while the wooden pyramid fell in the middle behind the control. However, higher germination synchrony (Z) was seen with both pyramids, copper and wooden respectively, when compared to the control. When examining coefficient of variation of germination time (CV_t) and uncertainty of germination (U), the copper pyramid saw the lowest variation of time and lowest uncertainty, followed by the control group and subsequently the wooden pyramid. All measurements of germination characteristics indicate longer incubation periods consistently provided better results than shorter incubation periods with few exceptions (see Table 9). Germination time, germination rate, variation of germination time, uncertainty, and synchrony were all improved in 35 and 45-day groups over the 5 and 10-day groups. Exceptions were seen in germination frequency and germination percentage, both of which were highest at 45 days followed by 5 days, 35 days, and 10 days. These results indicate pyramids cause more germination uniformity, and effects on these variables increase with longer incubation periods. We can accept hypothesis 1 and reject the null; pre-sowing incubation within a pyramid does have an effect on germination characteristics.

Objective 2 conclusions

Objective 2 sought to describe the impact of pre-sowing incubation within a pyramid regarding seedling growth. The conclusion can be drawn that the lowest tissue water content and highest vegetative growth was exhibited by the copper pyramid over the control group, while the wooden pyramid appeared to increase water content with less vegetative growth (see Table 10). In addition, the most vegetative growth was seen in shorter periods of incubation (5 and 10 days) when compared with longer periods (35 and 45 days) (see Table 11). This indicates copper pyramids are better than wooden pyramids when the goal is larger plant size, and shorter periods of incubation are more conducive to this goal. We can accept hypothesis 2 and reject the null; pre-sowing incubation within a pyramid does have an effect on seedling growth.

Objective 3 conclusions

Objective 3 sought to describe the impact of pre-sowing incubation within a pyramid regarding change in seed weight. Results indicate seeds stored within the pyramids saw a much larger increase in seed weight after charging than the control groups (see Table 12). The copper pyramid exhibited a larger increase in seed weight than the wooden pyramid. When examining length of incubation period, time spent in the pyramid seems to correlate with measured changes in weight of the seeds (see Table 13). A period of 45 days saw the highest change in seed weight while 5 days had the least change. This indicates copper pyramids paired with longer incubation periods may cause the highest increase in seed weight. We can accept hypothesis 3 and reject the null; pre-sowing incubation within a pyramid does have an effect on seed weight.

Objective 4 conclusions

Objective 4 sought to describe the impact of pyramid presence and construction material regarding soil condition. When measuring the temperature of soil that was stored within the pyramids, the wooden pyramid had the highest temperature while the copper pyramid exhibited the lowest temperature (see Table 14). This is in contrast with literature indicating all pyramids, regardless of material, have been shown to exhibit an increased temperature (Kumar et al., 2010; Kumar & Nagendra, 2011; Narimanov, 2000). As displayed by the ANOVA results (see Table 15), there were significant differences between the wooden pyramid and both other groups (copper pyramid and control). This indicates the wooden pyramid may be more adept at creating a favorable germination environment. We can accept hypothesis 4 and reject the null; pyramid presence and construction material effected soil condition.

Objective 5 conclusions

Objective 5 sought to describe any linear relationship existing between pyramid construction material, germination characteristics, seedling growth, and change in seed weight. Although results for the objectives above provided pyramid material had an effect on germination characteristics and seedling growth, further analysis using a one-way ANOVA pinpointed significant differences in germination percentage between the wooden and copper pyramid and between the copper pyramid and control group (see Table 16). However, there was no significant difference between the wooden pyramid and control group. Overall, results indicate copper pyramids are better than wooden at improving growth and increasing seed weight, while wooden pyramids create a warmer soil environment. Because germination results obtained herein are not consistent with previous findings, it can be hypothesized that the pyramids used in this study may not have been constructed as accurately as needed, or aligned with north properly to consistently influence plant growth. Regardless, we can accept hypotheses 5, 6, and 7: a relationship exists between pyramid material and germination characteristics, seedling growth, and seed weight.

Objective 6 conclusions

Objective 6 sought to describe any linear relationship existing between length of pre-sowing incubation period, germination characteristics, seedling growth, and change in seed weight. Results noted in the objectives above indicate length of incubation within a pyramid effected nearly all measured germination and growth characteristics. Results from several one-way ANOVA's revealed numerous significant interactions at the $p < .05$ level (see Table 17). Mean germination time, variation of germination time, germination rate, germination uncertainty, and tissue water content all indicated significant differences between 10 and 35 days of incubation within the pyramids. Germination uncertainty and synchrony noted significant differences between 10 and 45 days of incubation, and tissue water content further noted significant differences between 5 and 35 days of incubation. Change in seed weight was significant for all combinations of variations of incubation period. These results are in agreement with literature (Van Doorne, 2013) that length of time spent under a pyramid can increase the effects upon plants, while Bhat et al. (2010) noted time within a pyramid had no apparent effect on stress levels. These results indicate longer incubation periods have more effect on germination uniformity and seed weight, while shorter incubation periods primarily effect plant growth. We can accept hypotheses 8, 9, and 10: a relationship exists between length of incubation period and germination characteristics, seedling growth, and seed weight.

Implications

Objective 1 implications

Objective 1 sought to describe the impact of pre-sowing incubation within a pyramid on germination characteristics (G, MGT, CV_t, MGR, U, Z). Results indicate both wooden and copper pyramids negatively impacted germination frequency, germination percentage, mean germination time, and mean germination rate, but both pyramids increased germination synchrony. The copper pyramid also saw decreased uncertainty of germination and less variation in germination time over the control. This could mean pyramids create an atmosphere in which seeds germinate more uniformly with respect to synchrony, uncertainty, and variation of germination time. Results would surely differ if the experiment had been conducted outdoors where the pyramids could make direct contact with the earth. Brown (1978) indicates crop trials do well with copper pyramids, and thus pyramids may be shown to positively affect germination speed when in contact with the ground. As noted in the conclusion, most germination characteristics were improved at an amount that positively correlated with length of incubation period, while germination percentage and frequency both fluctuated seemingly with no pattern in relation to incubation period. Most literature suggested germination percentage should be improved in addition to other germination characteristics (Vasavada & Gadani, 2012;

Kumar et al., 2010; Kumar & Nagendra, 2011), although Schul and Pettit (1975) cautioned seeds within a pyramid sometimes exhibit slower germination.

Objective 2 implications

Objective 2 sought to describe the impact of pre-sowing incubation within a pyramid regarding seedling growth. Results indicate the copper pyramid was effective at increasing vegetative growth as was asserted by Flanagan (1973), Schul and Pettit (1975), and Brown (1978). It would be natural to hypothesize increased vegetative growth at the seedling stage could also result in higher plant yield in the production stage. Thus from the results of this study, it is an accurate assumption that pyramids have the potential to positively affect both plant growth and yield. These implications could contribute to a measureable decrease in world hunger, especially in developing regions such as SSA.

Objective 3 implications

Objective 3 sought to describe the impact of pre-sowing incubation within a pyramid regarding desiccation of seeds, serving as a germination trigger. In fact, the pyramids in this study actually had the opposite effect, in contrast with Narimanov (2000) who concluded pyramids aided seed desiccation. There could be many explanations for why the seeds gained weight such as absorption of moisture from the air, however seeds incubated within pyramids apparently gained weight at an increased rate over the control, and length of time within the pyramid further accelerated this difference. Although seeds did not appear to grow in overall size, an explanation for this effect could be influence of the magnetic field on seeds caused changes within the actual structure of the seed, such as changes noted in water (Cai et al., 2009; Gehr et al., 1995).

Objective 4 implications

Objective 4 sought to describe the impact of pyramid presence and construction material regarding soil condition. Because temperature is one of the key factors effecting seed germination (Washa, 2014), it would be of importance to determine whether the increased germination percentage and frequency exhibited by the wooden pyramid groups can be attributed to this increase in temperature within the pyramid environment. If so, measuring temperature would be an efficient and easy way to determine the expected performance of a pyramid when used for pre-sowing incubation of seeds. This technique would also be of practical importance in areas where chemicals have depleted soil, as growing plants within a pyramid would provide increased soil temperature and a more favorable germination environment.

Objective 5 implications

Objective 5 sought to describe any linear relationship existing between pyramid construction material, germination characteristics, seedling growth, and change in seed weight. Literature provided specific guidelines to be followed when constructing a pyramid, and material was noted as a significant factor by Toth and Nielson (1974) and Van Doorne (2013). Results from this experiment indicate wooden and copper pyramids did not have the same effects upon germination characteristics, seedling growth, or soil temperature. Further research is needed to identify how differences in material affect each stage of plant growth and how they affect plants of different species and varieties.

Objective 6 implications

Objective 6 sought to describe any linear relationship existing between length of pre-sowing incubation period, germination characteristics, seedling growth, and change in seed weight. Although most germination characteristics increased in correlation with longer incubation periods, effects seen from varying incubation pyramids differed according to the measured dependent variable. This indicates a shorter incubation period may be more beneficial for germination while a longer period may be more beneficial for growth (or vice versa). Effects could also differ depending upon genus, species, and variety of the seed or plant being grown. If optimum incubation periods can be identified that influence specific germination and growth characteristics, it would essentially be possible for farmers to combat a specific problem they have with a local plant variety, or even choose an incubation period for optimum germination rate or seedling growth in order to combat a short growing season or difficult weather patterns.

Recommendations

Objective 1 recommendations

Objective 1 sought to describe the impact of pre-sowing incubation within a pyramid on germination characteristics (G, MGT, CV_t, MGR, U, Z). These results indicate pyramids of both materials positively affect uniformity of seed germination, specifically synchrony, uncertainty, and variation of germination time. Although pyramids were seen to negatively affect measurements of germination speed and frequency, further research should be conducted on comparison between materials used in building pyramids as well as comparison between using pyramids on the ground versus on lab tables. It is also recommended that in-depth experiments take place examining the effect of incubation periods on seed germination characteristics. If an optimal building material and incubation period can be established, the effects on agricultural crops could be significant for both developed and developing countries. The use of pyramids and/or magnetism could be a promising addition to current agricultural practices as a way to increase crop yield and decrease production costs while combating world hunger.

Objective 2 recommendations

Objective 2 sought to describe the impact of pre-sowing incubation within a pyramid regarding seedling growth. From the results seen above, it is recommended to further study the effect of pyramids on seedling growth and yield. While this study only examined initial stages of seedling growth, a long term study could identify measurable differences in yield and possibly quality of harvest and produce.

Objective 3 recommendations

Objective 3 sought to describe the impact of pre-sowing incubation within a pyramid regarding desiccation of seeds, serving as a germination trigger. Conducting further studies will help determine the actual effects pyramids/magnetic fields have on seed physiology. If changes in germination and seedling growth can be attributed to changes within the seed structure, it would be important to note how and why these changes occur.

Objective 4 recommendations

Objective 4 sought to describe the impact of pyramid presence and construction material regarding soil condition. While the wooden pyramid exhibited increased internal temperature, it is recommended to further study all effects of pyramids and building materials on soil characteristics. Agronomists and soil scientists could experiment with a variety of plant and seed types to determine the magnitude of effects upon each when used in monoculture and modern farming. It may be possible to identify certain materials which are of benefit to specific crops.

Objective 5 recommendations

Objective 5 sought to describe any linear relationship existing between pyramid construction material, germination characteristics, seedling growth, and change in seed weight. The conclusions above maintain pyramids can have positive effects on seed germination and growth, however material used in building the pyramid can influence the outcome. Further research should be conducted into different pyramid materials and how they influence each stage of the seed germination and growth processes.

Objective 6 recommendations

Objective 6 sought to describe any linear relationship existing between length of pre-sowing incubation period, germination characteristics, seedling growth, and change in seed weight. Further studies should be conducted on varying incubation periods and combinations therein with different species of plants. As results indicated significant differences between short and long incubation periods, more specific time intervals should be analyzed.

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APPENDIX

APPENDIX A

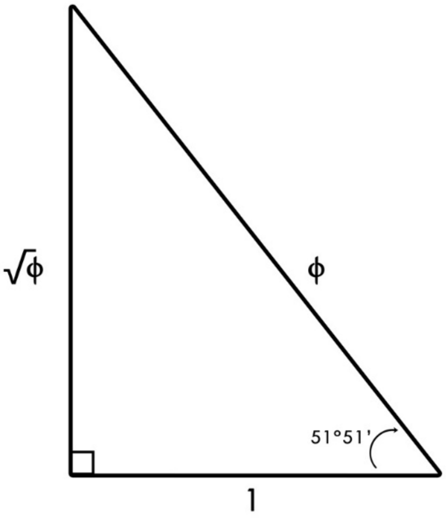

Figure 17. Phi value in a triangle

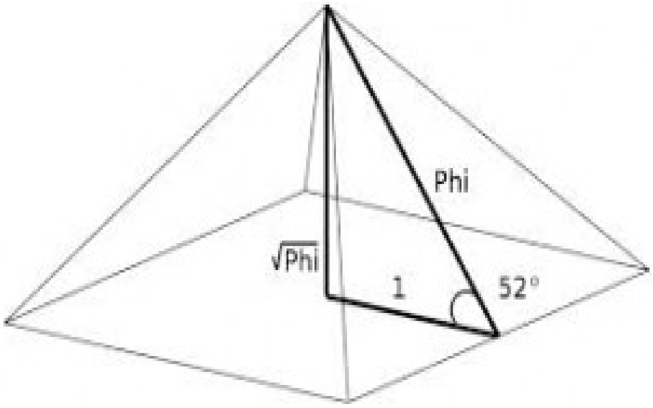

Figure 18. Phi value in a pyramid replica of the Great Pyramid of Giza

$$\phi = \frac{1+\sqrt{5}}{2}$$

$$\pi = \frac{4}{\sqrt{\phi}}$$

Figure 19. Phi calculation

Figure 20. Pi calculation

APPENDIX B

Manufacturer Information

Website: www.percival-scientific.com/

Phone: 800.695.2743

Address: Percival Scientific

505 Research Dr.

Perry, Iowa 50220

APPENDIX C

Table 18

Schedule of activities

	5	10	35	45
13-Jul				/charge (14:05)
14-Jul				charge 1
15-Jul				charge 2
16-Jul				charge 3
17-Jul				charge 4
18-Jul				charge 5
19-Jul				charge 6
20-Jul				charge 7
21-Jul				charge 8
22-Jul			/charge (14:30)	charge 9
23-Jul			charge 1	charge 10
24-Jul			charge 2	charge 11
25-Jul			charge 3	charge 12
26-Jul			charge 4	charge 13
27-Jul			charge 5	charge 14
28-Jul			charge 6	charge 15
29-Jul			charge 7	charge 16
30-Jul			charge 8	charge 17
31-Jul			charge 9	charge 18
1-Aug			charge 10	charge 19
2-Aug			charge 11	charge 20
3-Aug			charge 12	charge 21
4-Aug			charge 13	charge 22
5-Aug			charge 14	charge 23
6-Aug			charge 15	charge 24
7-Aug			charge 16	charge 25
8-Aug			charge 17	charge 26
9-Aug			charge 18	charge 27
10-Aug			charge 19	charge 28
11-Aug			charge 20	charge 29
12-Aug			charge 21	charge 30
13-Aug			charge 22	charge 31
14-Aug			charge 23	charge 32
15-Aug			charge 24	charge 33
16-Aug			charge 25	charge 34
17-Aug			charge 26	charge 35
18-Aug			charge 27	charge 36
19-Aug			charge 28	charge 37
20-Aug			charge 29	charge 38
21-Aug			charge 30	charge 39

Table 18 Continued

22-Aug		/charge (18:00)	charge 31	charge 40
23-Aug		charge 1	charge 32	charge 41
24-Aug		charge 2	charge 33	charge 42
25-Aug		charge 3	charge 34	charge 43
26-Aug		charge 4	charge 35/germ 1	charge 44
27-Aug		charge 5	germ 2	charge 45/germ 1
28-Aug		charge 6	germ 3	germ 2
29-Aug		charge 7	germ 4	germ 3
30-Aug	charge 1	charge 8	germ 5	germ 4
31-Aug	charge 2	charge 9	germ 6	germ 5
1-Sep	charge 3	charge 10/germ 1	germ 7	germ 6
2-Sep	charge 4	germ 2	germ 8	germ 7
3-Sep	charge 5/germ 1	germ 3	grow 1	germ 8
4-Sep	germ 2	germ 4	grow 2	grow 1
5-Sep	germ 3	germ 5	grow 3	grow 2
6-Sep	germ 4	germ 6	grow 4	grow 3
7-Sep	germ 5	germ 7	grow 5/dry 1	grow 4
8-Sep	germ 6	germ 8	dry 2	grow 5/dry 1
9-Sep	germ 7	grow 1	dry 3/FINAL	dry 2
10-Sep	germ 8	grow 2		dry 3/FINAL
11-Sep	grow 1	grow 3		
12-Sep	grow 2	grow 4		
13-Sep	grow 3	grow 5/dry 1		
14-Sep	grow 4	dry 2		
15-Sep	grow 5/dry 1	dry 3/FINAL		
16-Sep	dry 2			
17-Sep	dry 3/FINAL			

APPENDIX D

Table 19

Total number of germinated seeds, moldy germinated seeds, and non-germinated seeds

Pyramid Material	Incubation period	Replication	Germinated (total)		Germinated (moldy)		Non-Germinated (moldy, hard, dead)	
			#	%	#	%	#	%
w	5	1	49	98	0	0	1	2
w	5	2	49	98	0	0	1	2
w	5	3	49	98	1	2	1	2
c	5	1	48	96	0	0	2	4
c	5	2	49	98	0	0	1	2
c	5	3	49	98	1	2	1	2
x	5	1	50	100	0	0	0	0
x	5	2	49	98	0	0	1	2
x	5	3	50	100	1	2	0	0
w	10	1	49	98	1	2	1	2
w	10	2	50	100	0	0	0	0
w	10	3	48	96	0	0	2	4
c	10	1	48	96	0	0	2	4
c	10	2	44	88	0	0	6	12
c	10	3	49	98	0	0	1	2
x	10	1	50	100	0	0	0	0
x	10	2	49	98	0	0	1	2
x	10	3	50	100	0	0	0	0
w	35	1	49	98	0	0	1	2
w	35	2	49	98	0	0	1	2
w	35	3	49	98	0	0	1	2
c	35	1	50	100	0	0	0	0
c	35	2	47	94	0	0	3	6
c	35	3	48	96	0	0	2	4
x	35	1	50	100	0	0	0	0
x	35	2	49	98	0	0	1	2
x	35	3	49	98	0	0	1	2
w	45	1	50	100	0	0	0	0
w	45	2	50	100	0	0	0	0
w	45	3	50	100	0	0	0	0
c	45	1	50	100	0	0	0	0
c	45	2	47	94	0	0	3	6
c	45	3	47	94	1	2	3	6
x	45	1	50	100	0	0	0	0
x	45	2	50	100	0	0	0	0
x	45	3	50	100	0	0	0	0

APPENDIX E

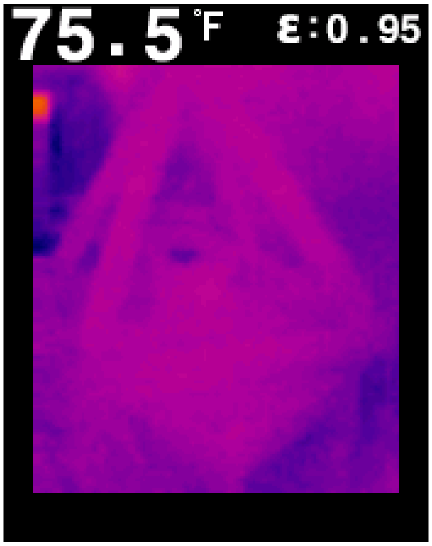

Figure 21. Infrared thermal image of wooden pyramid

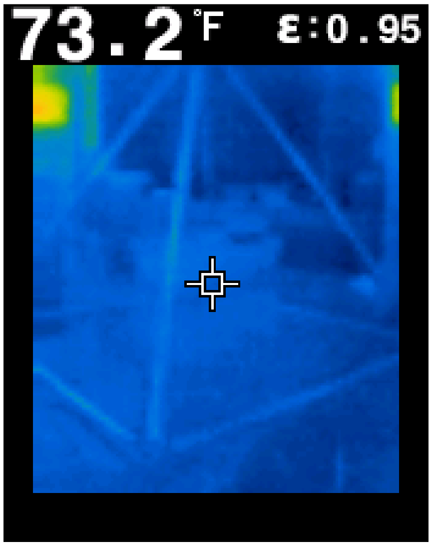

Figure 22. Infrared thermal image of copper pyramid

APPENDIX F

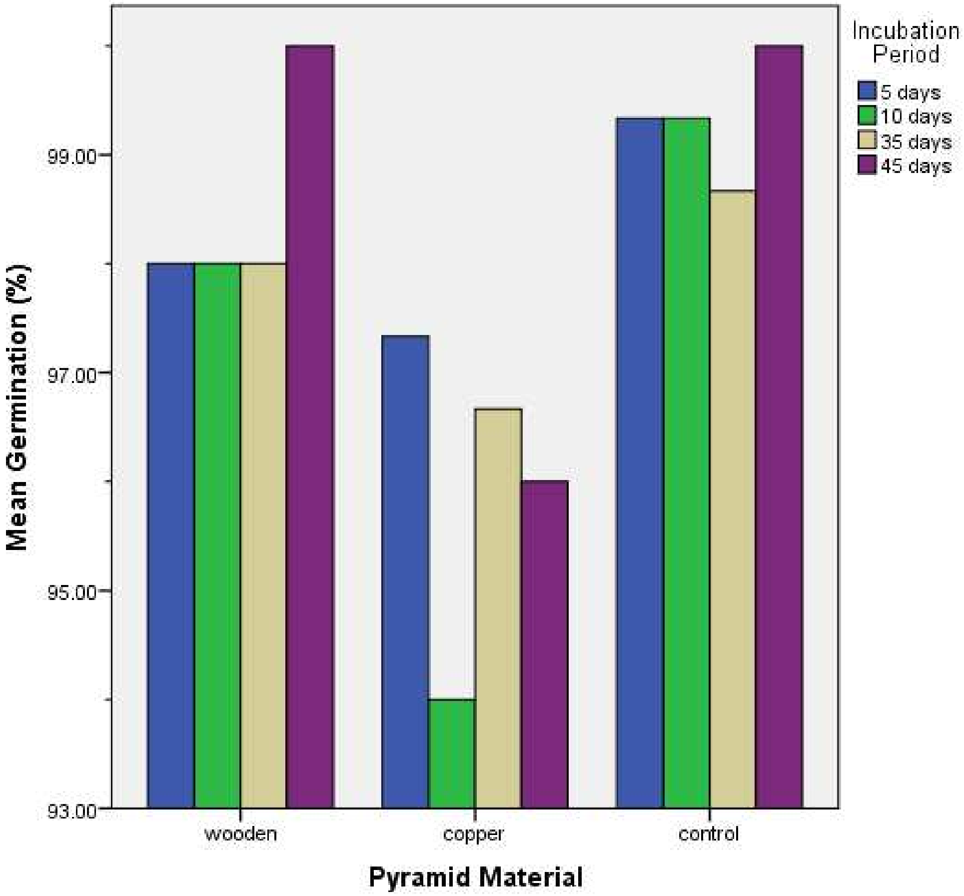

Figure 23. Mean germination percentage of seeds sorted by pyramid material and incubation period

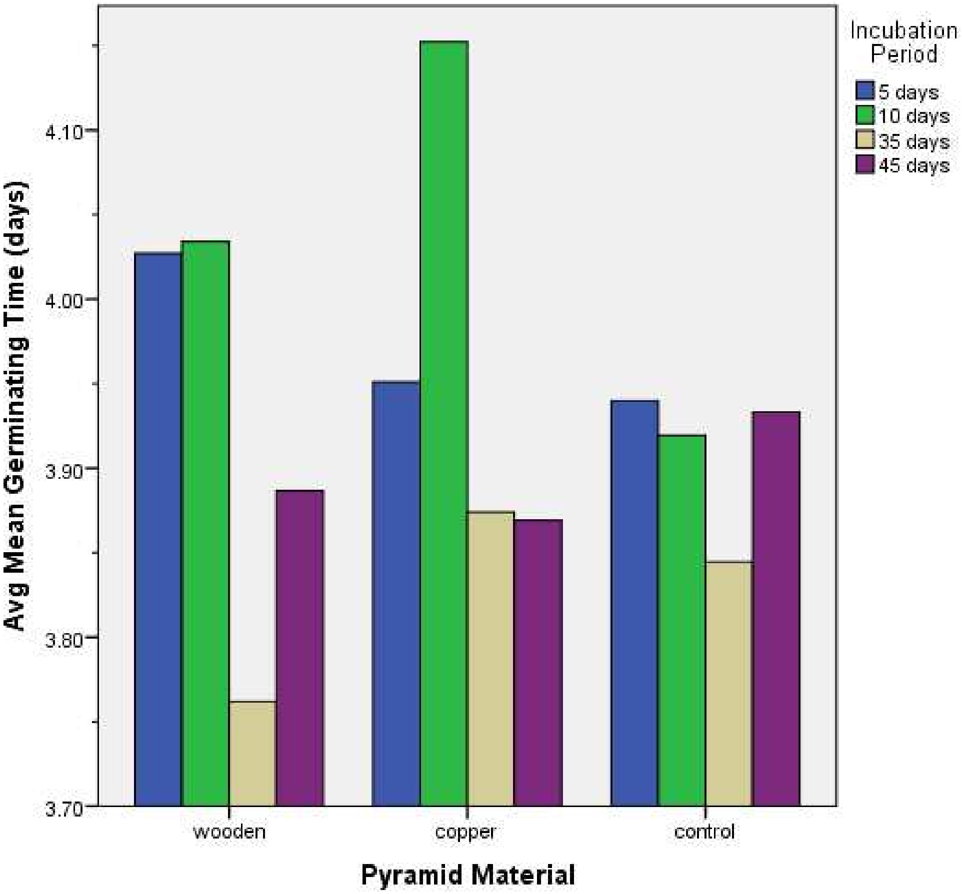

Figure 24. Mean germinating time of seeds sorted by pyramid material and incubation period

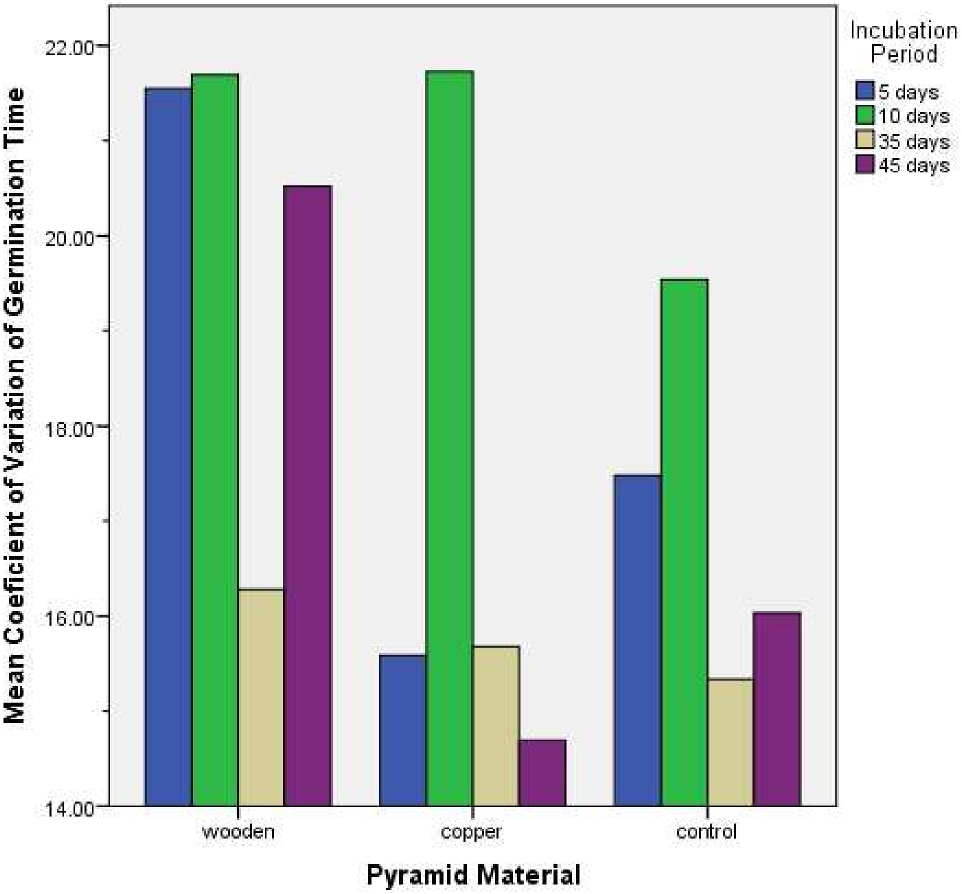

Figure 25. Mean coefficient of variation of germination time of seeds sorted by pyramid material and incubation period

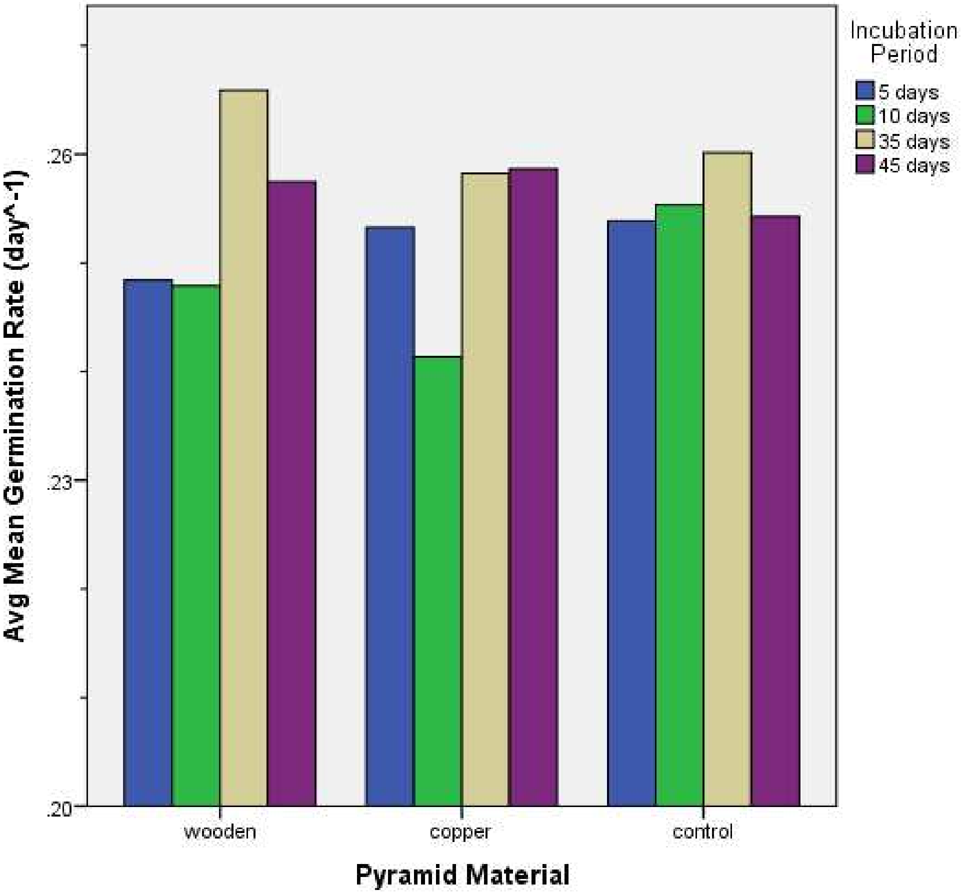

Figure 26. Mean germination rate of seeds sorted by pyramid material and incubation period

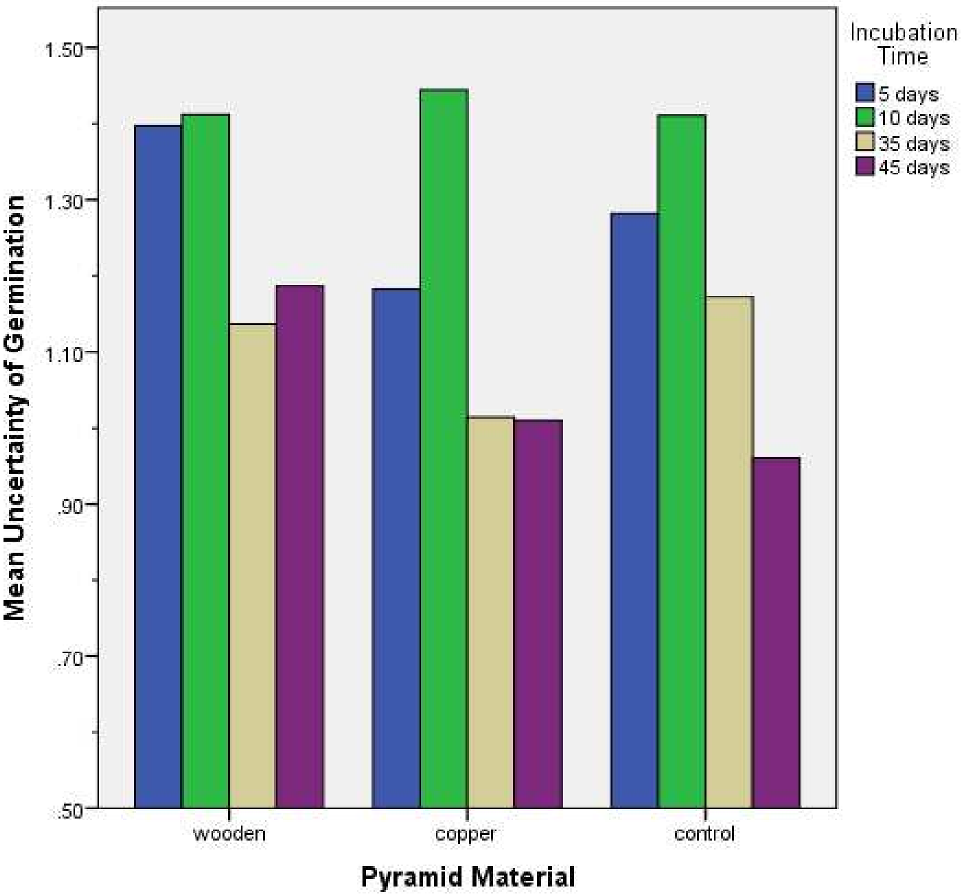

Figure 27. Mean uncertainty of germination of seeds sorted by pyramid material and incubation period

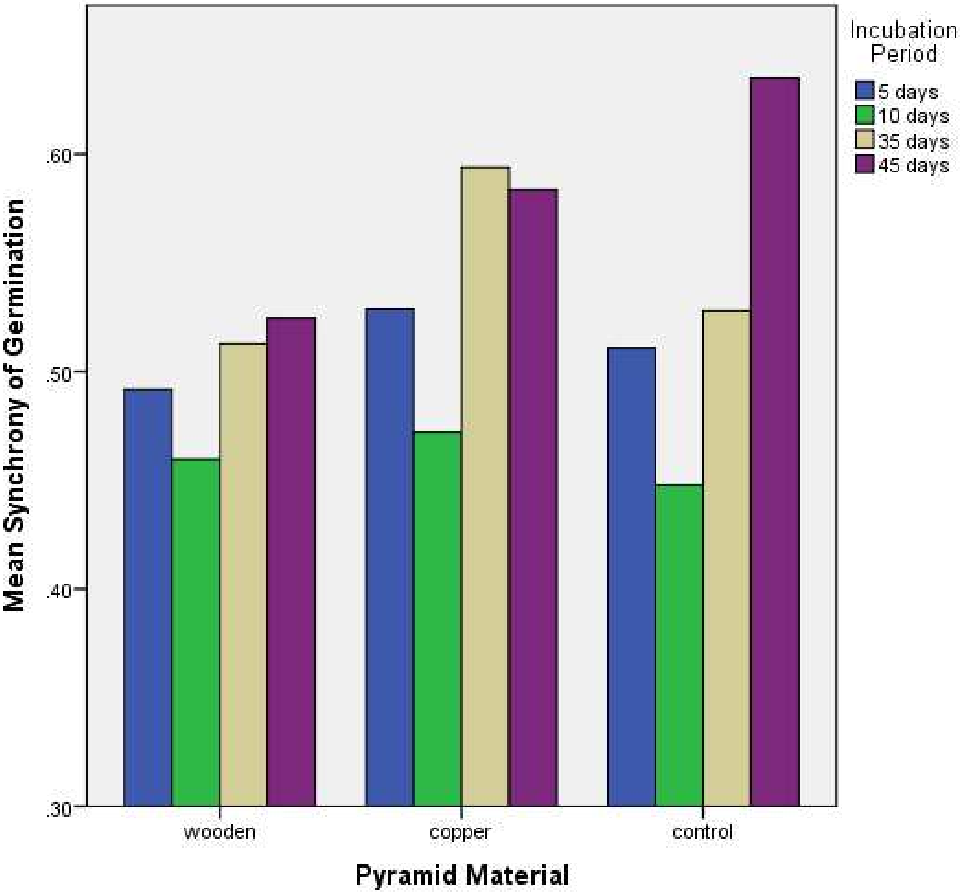

Figure 28. Mean synchrony of germination of seeds sorted by pyramid material and incubation period

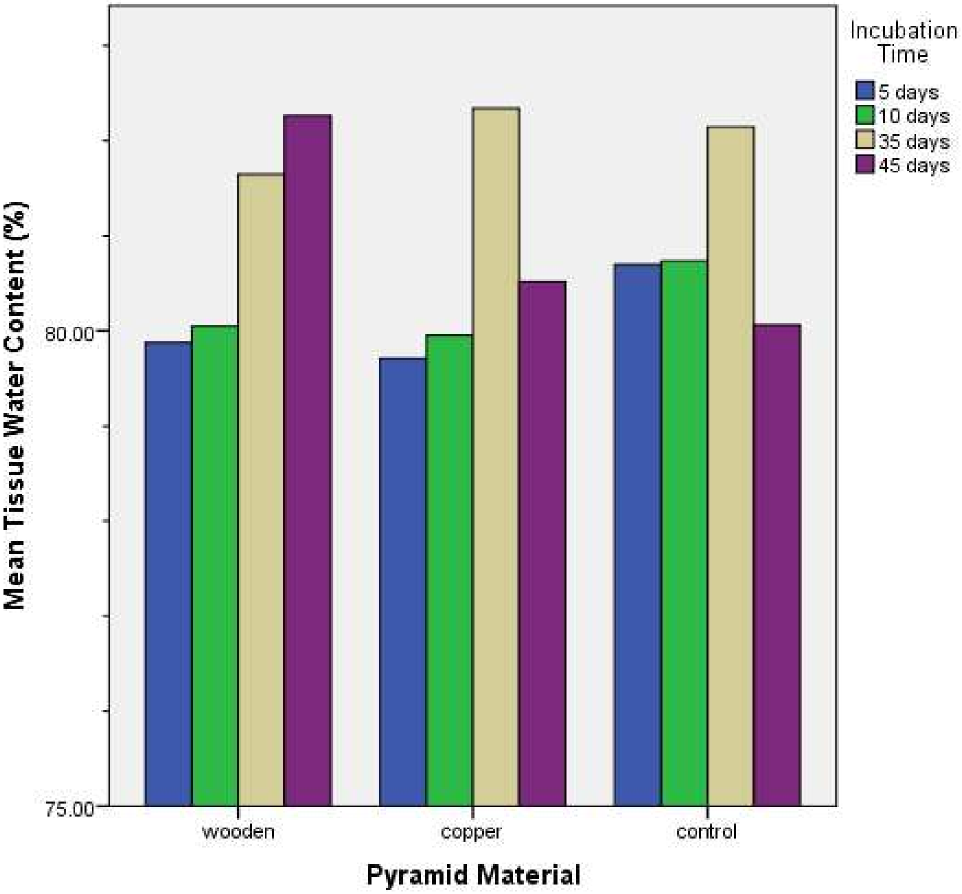

Figure 29. Mean tissue water content of seeds sorted by pyramid material and incubation period

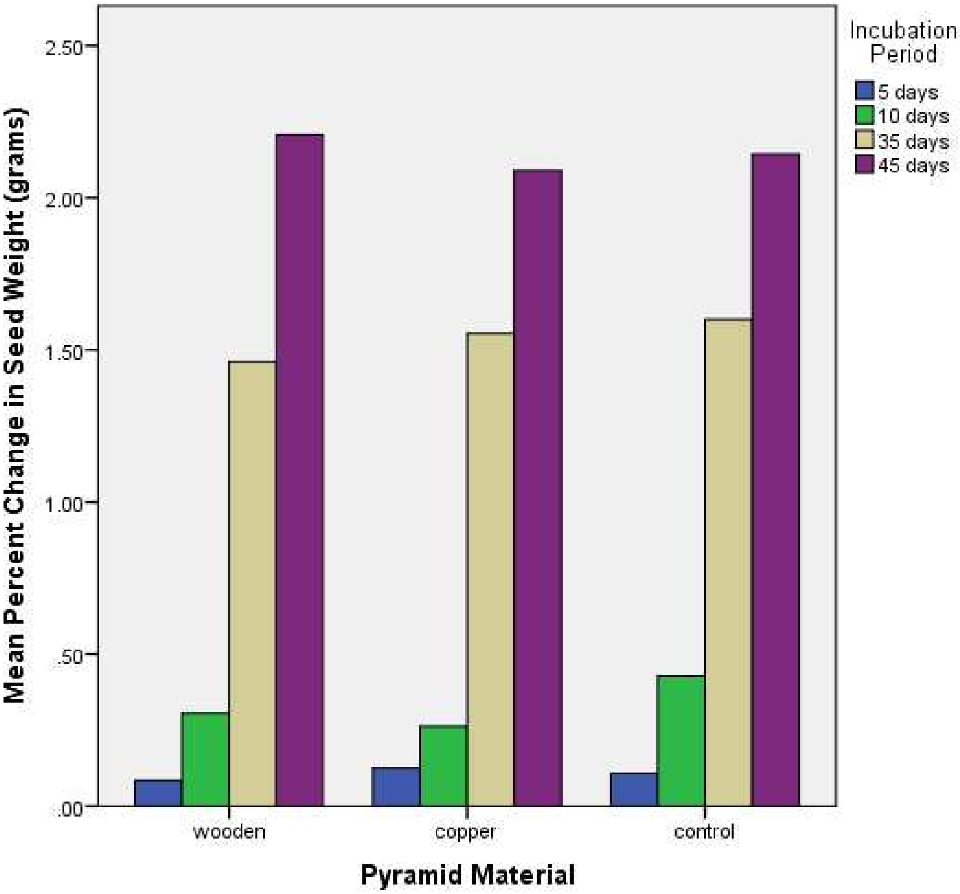

Figure 30. Mean percent change in weight of seeds sorted by pyramid material and incubation period

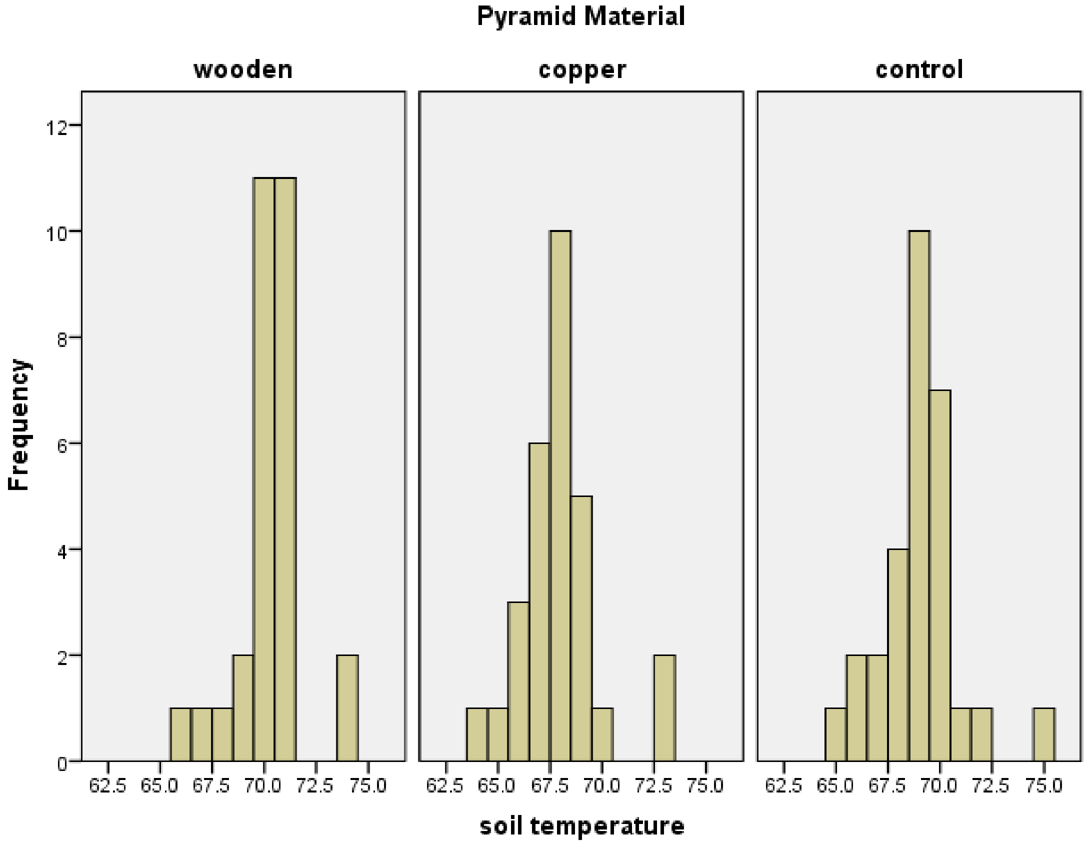

Figure 31. Frequency distribution of soil temperature measured under pyramids of varying materials