CHARACTERIZATION AND EVALUATION OF SUNFLOWER GERMPLASM FOR YIELD AND YIELD CONTRIBUTING CHARACTERS TO PERFORM WELL IN THE CONTEXT OF CLIMATE CHANGE IN BANGLADESH

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CERTIFICATE

This is to certify that thesis entitled, **“CHARACTERIZATION AND EVALUATION OF SUNFLOWER GERMPLASM FOR YIELD AND YIELD CONTRIBUTING CHARACTERS TO PERFORM WELL IN THE CONTEXT OF CLIMATE CHANGE IN BANGLADESH”** submitted to the Faculty of Agriculture ,Sher-e-Bangla Agricultural University, Dhaka, in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE** in the department of **Agroforestry and Environmental Science**, embodies the result of a piece of bonafide research work carried out by **TANIA SULTANA POPY**, Registration No. **13-05286** under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.

I further certify that such help or source of information, as has been availed of during the course of this investigation has duly been acknowledged.

....

Dated: July, 2019

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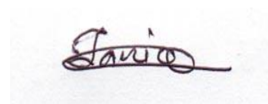
DECLARATION

I hereby declare that the thesis is based on my original work except for equations and citations, which have been duly acknowledged. I also declare that it has not been previously or currently submitted for any other degree at Sher-e Bangla Agricultural University or other institutions.



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Date: 21/10/2020

In the Name of Allah, Most Gracious, Most Merciful

Dedication

This thesis is dedicated to

My parents and my respective teachers

Their Sacrifice and Infinitive Love Led Me to Present this Achievement.

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Most importantly, none of this could have happened without my family. I would like to express my sincere and heartiest gratitude to my parents for supporting and guiding me in every step of my life, which made my higher education and also this study possible. To my parents and my brother – it would be an understatement to say that, as a family, we have experienced some ups and downs in the past three years. Every time I was ready to quit, you did not let me and I am forever grateful. This dissertation stands as a testament to your unconditional love and encouragement.

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The Author

CHARACTERIZATION AND EVALUATION OF SUNFLOWER GERMPLASM FOR YIELD AND YIELD CONTRIBUTING CHARACTERS TO PERFORM WELL IN THE CONTEXT OF CLIMATE CHANGE IN BANGLADESH

ABSTRACT

A study on characterization and evaluation of yield and yield contributing characters of sunflower germplasm was carried out by using twenty-one sunflower (*Helianthus annuus* L.) genotypes in 2018-2019 at the research field of Oilseed Research Centre (ORC), Bangladesh Agricultural Research Institute (BARI), Gazipur, Dhaka. The aim of this study was to characterize the sunflower germplasm according to their yield contributing characters, estimate association among plot yield and yield related traits and partition the correlation coefficients into direct and indirect effects and identify high yielding, dwarf and short duration sunflower genotypes for future trial. Data were collected on days to 50% flowering, days to maturity, plant height (cm), head diameter (cm), stem diameter (cm), number of seed/head, 1000 seed weight (g), seed weight/head (g), % oil content and yield/plot (g). Mean performance of Sunflower accessions, variability of quantitative and qualitative morphological characters, correlation coefficient analysis, path coefficient analysis and cluster analysis were estimated. The ranges for days to 50% flowering, days to maturity, plant height (cm), stem diameter (cm), head diameter (cm), number of seeds/head, seed yield/head (g) ,1000 seed weight (g), % oil content and yield/plot (g) were 64-93, 92-137, 72.8-160.4 cm, 0.96-2.22 cm, 7.2-16.6 cm, 19-303, 1.2-18.8, 25-80 g ,37.20-40.33% and 49-525.2g respectively. The genotype **ORCGP-21** produced taller plants of 160.4 cm and thicker stems of 2.22 cm. The genotype **ORCGP-2** and **ORCGP-13** produced maximum seed weight (80g). The genotype **ORCGP-15** produced maximum oil percentage (40.325%) than rest of the genotypes. For the trait of yield/plot, the genotype **ORCGP-21** produced maximum yield of 525.2g. Among the studied traits, high coefficients of variation were observed for the character seed yield/head (60.22g) followed by number of seeds/head (58.54) and plot yield (57.26 g). Plot yield was positively and highly significantly correlated with days to 50% flowering (0.55**), plant height (0.80**), stem diameter (0.56**), head diameter (0.40**), number of seeds per head (0.39**) and yield per head (0.34**).The path coefficient analysis showed that days to 50% flowering had the highest direct positive contribution on seed yield. Cluster analysis using R software classified the 21 sunflower populations into two main groups. A large number of accessions was placed in cluster V (6 accessions) followed by cluster I (5 accessions), cluster III (4 accessions) and cluster II and IV contains only three accessions. This result indicates a lot of diversity between these germplasm lines which can be exploited in future breeding program. The maximum genetic divergence was observed between cluster I and cluster V which may give rise to very good cross combination and desirable germplasms could be selected upon in the segregated generation. The accession **ORCGP-16** and **ORCGP-9** from cluster I and V respectively can be used in hybridization to synthesize new high yielding hybrids. The present study shows that short duration genotypes are **ORCGP-14, ORCGP-15, ORCGP-16** and high-yielding varieties are **ORCGP-6, ORCGP-10, ORCGP-11, ORCGP-12, ORCGP-16, ORCGP-21**. It indicates that the inclusion of these genotypes as potential germplasms for future hybridization program would result in the development of superior sunflower cultivars.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

%	-	Percentage (a rate, number, or amount in each hundred)
L.	-	Linnaeus
cm	-	Centimeter (a metric unit of length, equal to one hundredth of a metre)
g	-	Gram (a metric unit of mass equal to one thousandth of a kilogram)
Tk	-	Taka (the basic monetary unit of Bangladesh)
pH	-	potential hydrogen
ds/m	-	deciSiemens per metre
ha	-	hectare
B.C.	-	before Christ
m	-	meter
°C	-	Degree celsius
mm	-	milimetre
plants/m^2	-	Plants per meter square
PUFA	-	Poly Unsaturated Fatty Acid
kg/ha	-	Kilogram per hectare
TSP	-	Triple super phosphate
MP	-	Murate of Potash
ORC	-	Oilseed Research Centre
BARI	-	Bangladesh Agriculture Research Institute
DAE	-	Days after emergence
A.M	-	ante meridiem
DF 50%	-	Days to 50% flowering
DM	-	Days to maturity
PH	-	Plant height
HD	-	Head diameter
SD	-	Stem diameter
SH	-	No. of seed/head
SW	-	1000 Seed weight
OC%	-	Oil content %
PY	-	Plot Yield
CV	-	Coefficient of variation
SD	-	Standard deviation
F_1	-	First generation

CHAPTER 1

INTRODUCTION

Bangladesh is at risk of quickly ever-changing climate. Maple Croft's climate vulnerability index-2014 showed that Bangladesh hierarchal 1st among the 170 countries. Researchers demonstrated that over the last twenty years, soil and water salinity has raised sharply within the southwestern coastal region of Bangladesh. Salinity intrusion of this area hampers agricultural production that ordered most of the cultivable land stay fallow. Farmers of these regions cannot cultivate every type of crops during rabi season as a result of soil salinity, limitations of rain or irrigation and windy weather. This area could be brought under cultivation with appropriate oilseed crops that might increase the coverage and production of oilseed crops which will eventually fulfill the demand of edible oil.

In Bangladesh, acute shortage of edible oil has been prevailing throughout the last many decades (Khatun *et al*., 2016). According to Hossain (2014), Bangladesh produces 0.358 million tons of edible oil against a demand of 1.6 million tons. The remainder of 1.242 million tons is met up through foreign import. To meet the demand of edible oil, once a year Bangladesh Government has got to pay an enormous quantity of currency that price is around 1,38,141 million taka (BB, 2014).

The requirement of edible oil in Bangladesh could be changed by increasing the area and productivity of oilseed crops. But the horizontal expansion of oilseed crops area is too difficult due to declining per capita arable land as well as competition with rice-based cropping pattern. Moreover, the area under oilseeds cultivation is declining day by day due to various economical and technical reasons (Miah *et al*., 2014). However, oilseed cultivation area can be expanded by utilizing the fallow land and the lands where other crops are not fit to cultivate.

Sunflower (*Helianthus annuus* L.) is an oilseed crop (2n=34) belongs to family Asteraceae, tribe Heliantheae, which contains 20 genera (Deshmukh *et al*., 2016). It is native to temperate regions of North America, although was domesticated in Russia as an oil crop in the early eighteenth century. Now it is the world's 4^{th} largest source of oilseed crop (Masvodza *et al*., 2014) after Soybean, palm and rapeseed. During 2015-16, the total world production of sunflower oil was 1585000 tons (FAS, USDA, 2016) which accounts for about 14% of the total world oil production. Besides, sunflower also contributed a total of 7% oil cake worldwide (Masvodza *et al.*, 2014). Major sunflower growing countries in the world are Russia, CIS, Argentina, Europe, China, USA and India (Arshad *et al*., 2010).

Sunflower seeds contain about 50% of fat and 20% of protein. Sunflower oil is considered as premium oil as it contains high percentage of unsaturated fatty acids, light color, low quantity of linolenic acid, blend flavor and high smoke point. Oleic and linoleic acid are primary fatty acids (approximately 90% unsaturated fatty acids) in sunflower oil, however among others are palmitic and stearic saturated fatty acids (Arshad *et al.*, 2007).

Sunflower is a thermos-neutral crop, therefore, can be grown throughout Bangladesh both in rabi and kharif season. It is drought tolerant (Arshad *et al.*, 2019), can be cultivated in limited water area, and even in Barind tract as it requires less irrigation than other oilseed crops. It is a short duration crop (Arshad *et al*., 2019) which can be grown in between aman and boro rice. It can be grown in wide ranges of soil types (from sand to clay) along with a wide range of soil pH (5.7-8). Sunflower can tolerate approximately 2-12 dS/m threshold of salinity. Sunflower can be grown in the area of late rainfall or flooded areas where mustard or sesame is not possible to grow.

In Bangladesh Sunflower is a non-conventional oilseed crop which started to cultivate since 1975, but on a small scale (Habib *et al.*, 2007).The maximum area (4000 ha) and production (6000 tons) of sunflower was reported in year 2014-15, thereafter it has been declining gradually (Krishi Diary, 2019). The area under cultivation and production is decreasing mainly due to lack of high-yielding cultivars. High cost of imported hybrid seed, high harvesting cost and low net return to the farmers limits the production of this crop. The area and production of sunflower can be increased by high yielding potential varieties. For variety with high yield potential, it is essential to find out morphological and physiological traits as selection criteria which have strong correlation with seed yield (Škorić *et al*., 2002). Seed yield is a quantitative trait and it is dependent on many morphological and physiological characters (Arshad *et al*., 2007). Correlation between seed yield and yield contributing characters helps researcher to select desirable cultivar. Therefore, the present study has been taken to characterize and evaluate the sunflower germplasms for yield and yield contributing characters morphologically.

Keeping these points in view, the present investigation was performed with the following objectives:

1) To characterize the sunflower germplasm according to their yield contributing characters.

2) To evaluate their correlation between yield and yield components.

3) To evaluate direct and indirect effects of some characters on seed yield.

CHAPTER II

REVIEW OF LITERATURE

The scientific name of sunflower is *Helianthus annuus* which belongs to the family Asteraceae. The name “sunflower” is derived from the flower head's shape, which resembles the Sun. It is an annual plant grown as a crop for its edible oil. It is the world’s 4th largest most important oilseed crop after soybean, palm oil and rapeseed (Masvodza *et al.*, 2014). Sunflower oil is considered as premium vegetable oil throughout the world due to containing 90% of unsaturated fatty acid, 55-70% linoleic acid and 10% of saturated fatty acid (Bowers *et al*., 2012), vitamin E, no erucic acid as well as non-cholesterol and antioxidant properties. To grow best, sunflowers need full sun. They grow best in fertile, moist and well-soaked soil.

2.1. Sunflower in climate change context

Bangladesh is vulnerable to rapidly-changing climate. Maple Croft's Climate Vulnerability Index-2014 reported that among the 170 countries, Bangladesh ranked first and it will likely suffer more from climate change by 2025 compare to any other disaster-prone country. It is estimated that approximately 97.1 percent of the southwestern coastal region and over 35 million people living in those areas of Bangladesh are vulnerable and exposed to different climate change hazards. It has been demonstrated that salinity of both soil and water has increased sharply over the last 20 years in the southern coastal region of Bangladesh. Intrusion of salinity in that region hampers agricultural production and laid most of the arable land remains fellow. During the rabi season farmers of these region cannot cultivate all types of crops due to soil salinity, lack of sweet water to irrigate as well as windy weather. Brought under cultivation of this area by climate adaptive crop will increase the area and production of oilseed crops and which ultimately will reduce the gap between demand and production of edible oil.

Sunflower is a minor oilseed crop in Bangladesh and cultivating since 1975 in a small scale. It is a thermo neutral crop can cultivate both in rabi and kharif season. It is moderately drought tolerant crop and requires less amount of irrigation water. It can grow in a wide range of soil (from sandy to clay) with a wide range of soil pH (5.7-8.0). It can tolerate a salinity threshold level up to 12 ds/m, which might be considered as saline adaptive crop. Sunflower can be grown between T. aman and boro rice as it is a short duration crop. The area of late rainfall or flooded area also can be brought under sunflower cultivation where mustard or sesame is not possible to grow. Therefore, cultivation of sunflower would be a good substitute when it is difficult to cultivate other crops due to delayed rainfall or flooding, can be cultivate in the coastal environments, limited water area like Barind tract and in the area, where there are no crops after harvesting aman paddy. So, it can be said that sunflower might be considered as climate adaptive crop. Hence, the cultivation of sunflower would play a vital role in food security especially in the context of climate change in Bangladesh.

2.2. History and Origin of sunflower

Sunflower is native to North America and was carried by Europeans to various countries including Russia (Diane, 1995 and Rindels, 1996). It was first domesticated in North America around 3000 B.C. and then domesticated in southern Mexico which was proposed for second domestication area. In the late 1800s, the sunflower was introduced in the Russian Federation where it became a food crop and Russian farmers made significant improvements for the cultivation of sunflower.

2.3. Botany and Morphology of sunflower

The species *Helianthus annuus* belongs to family Asteraceae (synonym Compositae), genus *Helianthus* L. whose common name is sunflower. Its botanical name *Helianthus* comes from the Greek words '*helios'* (sun) and '*anthos'* (flower) (Siniša *et al*., 2015).

Sunflower is an annual, erect, herbaceous plant growing to a height of about 1.5 to 6.0 m. It has a tap and branched root system. Stem is 2.5 to 7.5 cm in diameter, rough hairy or hispid, usually without branches terminating in a capitulum or head. Sunflower leaves are simple, alternate with stout petioles, somewhat lanceolate in shape and about 5 to 25 cm long and two thirds as wide. Leaves are rough on both surfaces and irregularly toothed on the margins. Sunflower inflorescence is protandrous in nature, in which the male and female parts mature at different times. Head or capitulum shape varies, being concave, convex or flat consisting of numerous ray and disc florets. Heads are 10 to 30 cm in diameter with 40 to 80 rays and brown or black disc. The outer flowers are ray flowerets, which are sexually sterile and bright yellow, red and/or orange in colors. The flowers in the center of the head are called disk flowerets (Figure 1). The disk flowers are arranged spirally. Generally, each floret is oriented toward the next by approximately the golden angle, 137.5°. Each disk flower produces a one-seeded achene at its base, and these achenes are the source of sunflower seeds (Figure 2). The seed is monocarpellate (formed from one carpel) and indehiscent (they do not open at maturity). The entire head is subtended by numerous green bracts called phyllaries. During growth, sunflowers tilt during the day to face the sun but stop once they begin blooming. This tracking of the sun in young sunflower heads is called heliotropism. By the time they are mature, sunflowers generally face east.

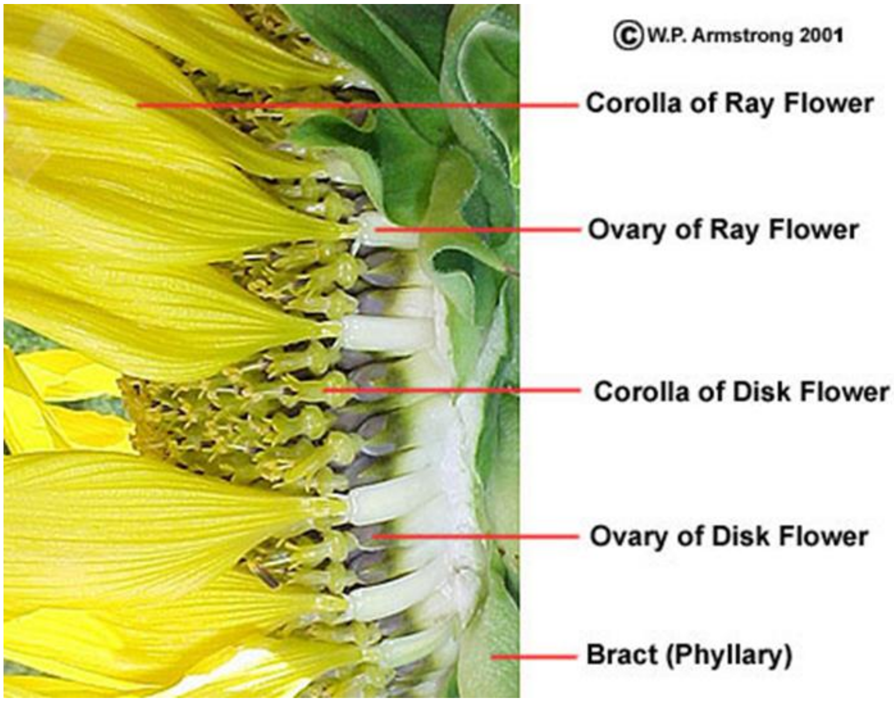

Figure 2.1: Close-up view of a portion of the flowering head of a sunflower (*Helianthus annuus*)

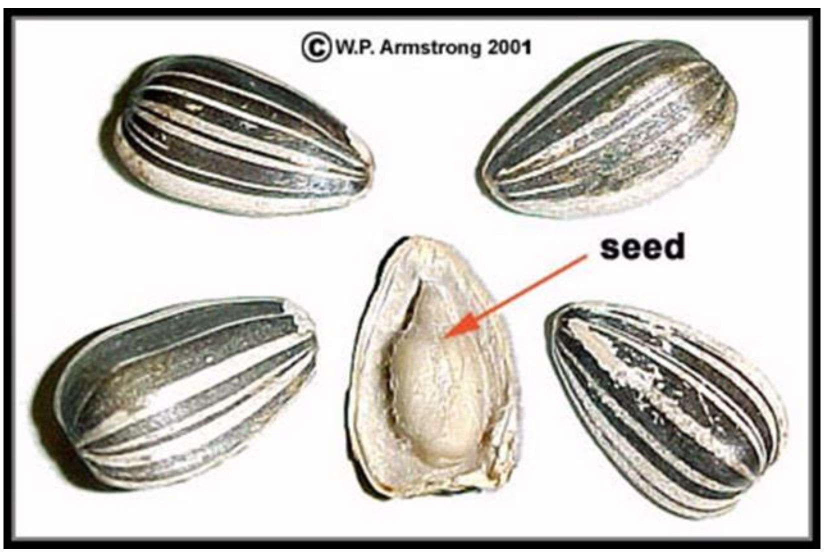

Figure 2.2: Achenes of the sunflower (*Helianthus annuus*). One achene has been sectioned to reveal the single seed inside.

2.4. Cultivation of Sunflower

Sunflowers are grown in warm to moderate semi-arid climatic regions of the world from Argentina to Canada and from Central Africa to the Commonwealth of Independent States (Esmaeli *et al*., 2012). The plant grows well within a temperature ranges from 20-25°C; temperature above 25°C reduce yields and oil content of the seeds (Thomaz *et al*., 2012). Plants are drought-resistant, but yield and oil content are reduced if they are exposed to drought stress during the main growing and flowering periods. Sunflowers produce moderate yields with as little as 300 mm of rain per year, while 500-750 mm is required for better yields (Ghaffari *et al.*, 2012; Gholam hoseini *et al*., 2013). Sunflowers adapt to a wide variety of soil, but perform best on good soils suitable for maize or wheat production (Radanielson *et al*., 2012). Plant density of 5-8 sunflower plants/m^2 is required to form the optimum leaf area for plant photosynthesis. Sunflower growth depends more on nitrogen than any other nutrient. The plant requires a maximum of 150 kg of nitrogen per hectare to produce 3 ton/ha yield. It has ability to use nitrogen from different soil layers due to its deep rooting system. Sunflower has the shortest growing seasons compared to the major economically important crops of the world. Early maturing varieties are harvested at 90 to 120 days after planting.

2.5. World area and production of sunflower

Recently, world-wide sunflower is cultivating in an area of about 26 million hectares with an annual production of 45 million tons (Konyalı, 2017).

In recent years, the area under sunflower cultivation has been steadily increasing due to the breeding of dwarf high yielding hybrids that also facilitate mechanization and the emphasis given to polyunsaturated acids for human consumption. Global production grew steadily in last 25 years (PSD-USDA, 2011), and FAO expect a total world output close to 60 million tons towards 2050. The four largest producers (Russia, Ukraine, European Union and Argentina) account for 70% of global volume, with an exponential growth of production in the last ten years in the Black Sea region, with increased acreage an higher yields achieved by the replacing old varieties by hybrid seeds.

According to data from FAOSTAT (FAOSTAT, 2011) Russia Federation ranked first producing ca. 9.7 millions of tons of sunflower seeds or 26% of the world total. Ukraine and Argentina ranked second and third place with 8.6 and 3.6 tons of sunflower seeds, respectively. France, Romania, China, Bulgaria, Hungary, Turkey, and Spain produced between 1.0 and 1.9 millions of tons of sunflower seeds.

2.6. Economic Importance of sunflower

Sunflower is a distinctive, flowering seeds of which contain valuable edible oil and Vitamin E than any other vegetable oil. Sunflower seed is the source of 82% of all edible oil produced in South Africa. The oil composition consists of 90% oleic and 10% linoleic acids or vice versa. Protein contents of the seed ranged from 20-30%. In Europe, Sunflower oil is the second most widely used oil after rapeseed. Oil cake is the by-product of sunflower oil extraction and is a source of protein for animal feed blends. The value of sunflower oil cake is equivalent to 72% of the value of soybean oil cake. Sunflower oil is considered as premium because of its high PUFA (Poly Unsaturated Fatty Acid) content with high level of linoleic acid. Because of this, its use in diet reduces the level of blood cholesterol.

There are two types of sunflower seeds produced: oilseed and confectionary. Sunflower seeds can be dried or roasted and used as a medicine in South America. Sunflower oil has cleansing properties: it is both a diuretic and an expectorant. Sunflower seeds are very rich in protein and in essential fatty acids. These nutrients are essential for the good health of the nerves, brain and eyes and for the general health.

2.7. Uses of Sunflower

At present, sunflower has become popular as a feedstock crop because of sharing several positive agronomic features with other common oil crops such as canola (a hybrid of rapeseed) and soybean. A number of crops can be used for both food and bioenergy production such as sunflower (Kibazohi *et al.*, 2012) which was already been used in ancient ceremonies (Harter *et al.*, 2004; Muller *et al.*, 2011). For instance, Native Americans used sunflower plants for treating a variety of ailments. In Mexico and North America, sunflower seeds were roasted and beaten into a paste before being boiled in water; the oil that rose to the surface was skimmed off (FAO, 2010). Sunflower seeds are an excellent source of vitamin E, the body's primary fat-soluble antioxidant which has significant anti-inflammatory effects and plays an important role in the prevention of cardiovascular disease. Refined Sunflower seed contains 39 to 49% oil which is used for the production of paint, varnish and soap. Additionally, some parts of this plant are used in making dyes for the textile industry, body painting and medical uses for pulmonary afflictions have also been reported. Sunflower oil is generally considered as a premium oil because of its high level of unsaturated fatty acids and lack of linolenic acid (oil composition can be 20-60% linoleic acid and 25-65% oleic acid, protein content is 15-20%) that is used in salad dressings, for cooking and manufacture of margarine and shortening (Kunduraci *et al*., 2010). The remaining material after oil extraction has a protein content of 28-45% which is used as cattle feed. A coffee type could be made with the roasted seeds. In some countries, the seed cake that is left after the oil extraction is used as livestock feed. The stems contain phosphorous and potassium which can be composted and returned to soil as fertilizer. The dried stems is used for fuel. Sunflower meal is a potential source of protein for human consumption due to its high nutritional value and lack of anti-nutritional factors (Fozia *et al.*, 2008).

2.8. Relationship between yield and yield contributing characters

2.8.1. Study of correlation

Yield is a complex character which is a function of several component characters and their interactions with environment. It is necessary to measure the mutual relationship between various plant characters and determine the component characters on which selection can be based for yield improvement. Genotypic and phenotypic association reveal the degree of association between different characters. Thus it helps to base selection procedure to a required balance where two opposite desirable characters affecting the principal characters are being selected. Many researchers have used correlations to examine the relationships among yield components in sunflowers (Kaya *et al*., 2003, Joksimovic *et al*., 2004, Hladni *et al*., 2004, Dušanić *et al*., 2004). The yield-contributing characters are days to flowering, days to maturity, plant height, head diameter, stem diameter, number of seeds per head, 1000 seed weight, total dry matter per plant, % oil content and seed yield per plant etc.

Patil,(2011); Sowmya *et al*., (2010); Machikowa and Saetang, (2008); Kaya *et al*., (2007); Hladni *et al*., (2006); Srimuenwai,(2006); Khokhar *et al*., (2006) studied the yield contributing characters of sunflower and reported that seed yield per plant was significantly and positively correlated with number of leaves per plant, plant height, stem diameter at top height, stem diameter at mid height, head diameter, head diameter of sterile area, weight of head, number of seeds per head, leaf length, leaf breadth and leaf area.

Plant height had negative and significant correlation with head diameter was stated by Sujatha and Nadaf, (2013).On the contrary, Tahir *et al*., (2002) reported that plant height was positively correlated with head diameter at both phenotypic and genotypic levels. Plant height has significant and positive correlation with seed yield at genotypic level, while positive but non-significant correlation at phenotypic level. Narayana *et al*., (1998) reported that seed yield was positively and significantly associated with plant height. Arshad*et al*. (2007) studied and found that plant height and seed yield was negatively correlated at both phenotypic and genotypic levels. Plant height had highly significant and positive correlation with days to flowering at genotypic level, while significant at phenotypic level. Marinković & Dozet (1997) reported that the plant height was negatively correlated with harvest index and lodging resistance. They found that sunflower breeding is improved harvest index and lodging resistance via reduced plant height. Marinković *et al*., (2002) reported that in regions with strong winds and heavy precipitation some genotypes are exposed to lodging which reduce yield and seed quality.

Tahir *et al*., (2002) reported that head diameter has direct and indirect correlation on seed yield per plant via number of flowers and filled seeds per head. Yasin & Singh (2010) and Behradfar *et al*., (2009) studied the correlation between head diameter and seed yield and reported that head diameter had positive and highly significant correlation with seed yield. Tahir *et al*., (2002) and Khan *et al*., (2005) reported that head diameter had significant and positive correlation with 1000 seed weight but Ozer (2003) reported that the correlation between head diameter and 1000 seed weight was insignificant. Khan *et al.*, (2003), Ozer *et al*., (2003) and Sridhar *et al*., (2005) reported that head diameter had positive and significant correlations with achene yield of sunflower. Amorim *et al*., (2008) observed a significant correlation between head diameter with seed yield and Machikowa *et al*., (2008) showed that seed yield was strongly correlated with head diameter, seed weight and plant height. On the other hand, Patil *et al*., (1996) reported that there was a negative correlation between seed yield and head diameter. Furthermore, Varshney *et al*.,(1977) could not find any correlations between the seed yield with head diameter of sterile area, head diameter, total weight of head, and with the number of seeds per head .

Abrar *et al.* (2010) found that seed yield was positively and significantly correlated with plant height, number of filled seeds, head diameter, seed weight, and harvest index. Significant positive association of seed yield was observed with number of filled seeds per head and test weight, whereas, negative association was observed with number of unfilled seeds per head. Number of filled seeds per head recorded highest positive correlation with seed yield. This is in conformity with the results of other workers (Punia and Gill, 1994; Teklewold *et al*., 2000;, Nehru and Manjunath, 2003; Sridhar *et al*., 2005 and Vidhyavathi *et al*., 2005).

Singh (2010) found negative non-significant correlation between number of seed per head and seed weight and head weight with seed weight. .Tyagi *et al.* (2013) found that number of seed per head had positively and highly significantly correlated with seed yield per plant and positively with number of leaves per plant.

Tyagi *et al*. (2013) founddays to 50 % flowering were significantly and positively associated with seed yield.

Habib *et al*. (2007) showed the genetic correlations of stem diameter, head diameter, number of seeds per head positive and significant with seed yield.

Gjorgjieva *et al*. (2015) observed that seed weight was positively and significantly correlated with seed yield.

Seed yield was positively correlated with oil content, plant height, and seed weight, but 50% days to flowering correlated negatively with seed yield (Kaya*et al*., 2003).

Mamta *et al*. (2017) found that seed yield had positive non-significant correlation with 50% days to flowering. Days to 50% flowering showed negative and significant correlation with head diameter and seed weight reported by (Sujatha and Nadaf, 2013).

Seed yield was significantly and positively correlated with head diameter and seed weight reported by Sujatha and Nadaf (2013). Head diameter had positive and significant correlation with seed yield per plant and seed weight (Anandhan *et al*., 2010).

Muthupriya *et al*. (2016) found that head diameter had positive significant correlation with seed weight and seed yield per plant, head diameter, seed weight, and seed yield, and strong and positive association with yield and oil yield.

Anandhan *et al*. (2010) found positive correlation between seed weight with seed yield per plant and oil yield while seed yield positive non- significant with plant height and volume weight.
The positive association of days to maturity was noticed with days to 50% flowering, plant height and number of leaves per plant with the findings of Sridhar *et al*., 2005.

The significant positive association of number of filled seeds per head and head diameter with seed yield was observed by Teklewold *et al*. 2000; Sridhar *et al*. 2005 and Vidhyavathi *et al*. 2005.

Anandhan *et al*. (2010) reported the strong positive correlation of oil yield with seed weight, volume weight, and seed yield per plant. The positive association of oil content with number of unfilled seeds, test weight and seed yield was observed by Rao (1987)). However, negative association between seed yield and oil content was reported by Vidhyavathi *et al*., (2005), Habib *et al*., (2007), Arshad *et al.*, (2010) also reported that seed yield expressed negative and highly significant genotypic and phenotypic association with oil content.

Amin *et al.*, (2016) found positive correlation between head diameter with stem diameter and seed weight with plant height and stem diameter.

Kaya *et al*., (2009) and Arshad *et al*., (2007) reported that days to flowering showed negative but non -significant correlation with seed yield.

Ozer *et al*., (2003) reported that seed yield, stem diameter, number of day to physiological maturity have significant correlation with seed yield, respectively.

Abrar *et al.,* (2010) reported that highly significant and positive correlation between seed yield with number of seeds per head, head diameter and seed weight at both genotypic and phenotypic levels

Chikkaderaiah and Nadine (2002) studied on yield and it's parts in 54 sunflower genotypes and reported that oil yield and 1000 seed weight have significant correlation with seed yield/head.

Godwa (1994), Manjula (1997) , Rao *et al*., (2003), Sridhar *et al*., (2005), Machikowa and Saetang (2008), Tyagi and Tyagi (2010), Pandya *et al*., (2016) reported that seed yield per plant performed highly significant and positive correlation with days to 50% flowering, days to maturity, number of leaves per plant, stem girth, head diameter, 100 seed weight, seeds per head, filled seeds per head and harvest index at genotypic and phenotypic levels indicating an increase in seed yield with strong selections of these characters.

Hladni *et al*., (2011) reported that seed yield and the 1000- seed weight had a large influence on the crude protein yield of confectionary sunflowers.

The genotypic and phenotypic correlations between head diameter and the traits 100-achene weight, number of achenes per head, oil yield ha^{-1} and seed yield per plant was found positive and significant reported by Narayana and Patel (1998) and Singh *et al*., (1998).

2.8.2. Study of path coefficient

The use of simple correlation analysis sometimes could not fully explain the relationships among yield characteristics. Path coefficient analysis helps researchers to explain the direct and indirect effects for a more and complete determination of the impact of independent variable on dependent one among important yield traits (Singh and Chaudhary, 1979). Seed yield is a quantitative character and it is influenced more from environmental factors in sunflower due to control of large number of genes. To separate correlation coefficients into components of direct and indirect effects, the path-coefficient analysis is an excellent tool because it can measure the direct and indirect effects of interrelated components of a complex trait like yield (Chaudhary, 1993; Punia and Gill, 1994). Head diameter, 1000 seed weight, plant height are valuable yield parameters to determine for yield improvement in the sunflower (Miller and Fick, 1997). In agriculture, path analysis has been used by researcher to assist in identifying traits that are useful as selection criteria to improve crop yield (Milligan *et al*., 1990).

Nehru and Manjunath (2003) , Sridhar *et al*., (2005) , Vidhyavathi *et al*., (2005), Arshad *et al*., (2010), Sowmya *et al*., (2010), Kholghi *et al*., (2011) , Patil (2011) , Neelima *et al*., (2012) studied the path analysis in sunflower and reported that the head diameter, plant height, days to 50% flowering and seeds per head had strong positive direct effects on seed yield per plant whereas days to maturity and oil content showed moderate to low positive direct effects. On the contrary, negative and low to negligible direct effects were observed for number of leaves per plant, stem girth, leaf area, 100 seed weight, filled seeds per head and harvest index. The indirect effects of head diameter, plant height, days to 50 percent flowering, seeds per head and days to maturity were higher and positive for most of the characters, which were identified as the most important yield components. These findings suggested that, selection pressure should be given to head diameter, plant height, days to 50 percent flowering and seeds per head would be effective for improvement of seed yield in sunflower.

Abrar *et al*. (2010) reported that number of seeds per head, 1000-seed weight and head diameter had the highest and positive direct effect on seed yield.

Alvarez *et al*. (1992) indicated that indirect selection of morphological traits in sunflower, particularly head diameter, improved seed and oil yields with greater efficiency than direct selection. Also, a path coefficient analysis by Punia and Gill (1994) on 63 genotypes indicated that number of seeds per head, 100-seed weight and head diameter were most important traits contributing to seed yield.

Habib *et al*. (2007) showed that direct selection of traits like number of seeds per head and 100-achene weight can improve seed yield.

Gjorgjieva *et al*. (2015) reported that 1000-seed weight expressed the highest positive direct effect on seed yield.

Machikowa *et al*. (2008) reported that head diameter showed the highest positive direct effect on seed yield followed by plant height. In addition, the indirect effects of most characters were plant height through head diameter.

Sridhar *et al*., (2005) reported that plant height, head diameter and 100 seed weight had positive direct effect on seed yield per plant indicating that yield was a function of both growth and yield components.

Rao (1987) studied the relationship of leaves per plant with grain yield per plant and reported that leaves per plant has negative direct effect with grain yield per plant but it's correlation coefficient is positive. This result indicates that some indirect effects seems to be the cause of correlation. In this situation, one should consider all the indirect causal factors, which effects grain yield positively during selection.

Singh *et al.*, (1977) reported that days to maturity has positive direct effect on grain yield per plant, while positive indirect effect via plant population m^{-2}, leaves $plant^{-1}$, plant height and oil content and negative indirect effect through days to flowering, head diameter, seeds $head^{-1}$ and 1000-seed weight, while deviate from those of Naeem and Farhatullah (1986), Rao (1987) and Muhammad *et al*., (1992).

Kotecha (1980), Beard and Geng (1982), Pathak *et al.*,(1983)and Punia and Gill (1994) reported that Number of seeds per head showed positive and significant correlation with grain yield per plant. Alvarez *et al*., (1992) and Punia and Gill (1994) reported that the direct effect of number of seeds per head is positive.

Rao (1987) stated that Correlation between 1000-seed weight and grain yield per plant is positive but non-significant. The direct effect of 1000-seed weight was positive and high as reported by Alba *et al*., (1982), Sadaqat and Khalid (1987) and Punia and Gill (1984), Fick *et al*., (1974), Beard and Geng (1982), Rao (1987) and Chaudhary and Anand (1993) reported that Oil content had highly significant positive correlation with grain yield per plant. While Alba *et al*., (1982) and Rao (1987) found negative direct effect of oil content on grain yield.

CHAPTER III

MATERIALS AND METHODS

The experiment was conducted during the rabi season of November 2018 to March 2019 to characterize and evaluate the sunflower germplasm/lines for yield and yield contributing characters under field condition. This chapter describes a short description of the experimental site, climate, soil, experimental materials, methods of the study, data collection procedure and procedure of data analysis. The detailed materials and methods that were used to conduct the study are presented below under the following headings:

3.1 Site description

The experiment was conducted at the research field of Oilseed Research Centre, BARI, Gazipur which is located at the center of the Agro-ecological zone of Modhupur Tract (AEZ-28) at about 23°59´15´´ north latitude and 90°24´20´´ east longitude having a mean elevation of 8.8 m above mean sea level (UNDP - FAO, 1988). The soil belongs to Chhiata series of the gray terrace soils (*Aeric Albaquept*), the textural class was clay loam having soil pH 6.2 and land type was medium high (Huq and Shoaib, 2013). The monthly weather data during the crop growing period from November to March, 2018-2019 was presented in Table 3.1.

Table 3.1: Monthly weather data during the crop growing period of 2018-19

Month	Temperature (°C)		Humidity (%)		Rainfall (mm)	Sunshine (hr)
	Max	Min	Max	Min		
November	30.91	18.33	89.36	72.63	0.00	8.09
December	26.51	15.17	92.27	74.34	8.50	5.54
January	23.75	10.55	90.09	66.74	0.00	6.27
February	29.11	15.26	88.03	53.35	4.50	6.41
March	30.09	19.37	86.6	51.00	7.50	7.34

3.2 Land preparation and fertilization

The experimental land was well prepared by ploughing with tractor and power tiller followed by laddering and cross laddering. At that time all the debrises and uprooted weeds were removed from the field. Fertilizers were applied @ 180-200, 160-200, 150-170, 150-170, 8-10, and 10-12 kg/ha of urea, TSP, MP, Gypsum, Zinc sulphate and Boric acid. A total of 8-10 ton/ha cowdung was also applied. Half of the Urea and full amount of the other fertilizers were applied at the time of final land ploughing and were mixed with soil by laddering and cross laddering. The land was divided into small plots which help in irrigation, drainage and other intercultural operations. Rest half of the urea was applied as top dress during 20-25 days after emergence as first time and second time at 40-45 days after emergence.

3.3 Collection and sowing of seeds

For agro-morphological characterization, the seeds of 21 sunflower genotypes were collected from Oilseed Research Centre (ORC), BARI, Joydebpur, Gazipur. Before sowing, seeds were treated with Vitavex-200 @ 3 g/kg seed to protect the seeds from soil and seed borne diseases. The seeds were grown in the research field of ORC, BARI, Gazipur on 19 November 2018. Two rows of each entry were sown with 50 cm row to row distance and 25 cm plant to plant distance. The size of unit plot was 4m×2m and the distances between plot to plot were maintained 1.5m. Three to four seeds were sown per hill to facilitate better emergence and to maintain uniform stand.

3.4 Intercultural operations

The experimental plots were always kept under careful observation. After emergence of seedlings, the following intercultural operations were accomplished for their better growth and development of the plant.

3.4.1 Thinning

One healthy seedling/hill were kept for future growth and development. Excess seedlings were removed within 15-20 days after emergence.

3.4.2 Irrigation

After full emergence (20-25 DAE), the crop was irrigated by flooding so that uniform growth and development of the crop was occurred and also moisture status of soil retain as per requirement of plants. In total, thrice time (25, 50 and 70 days after sowing) of irrigation were applied throughout the whole cropping period.

3.4.3 Weed control

Weeding was done as and when necessary to keep the crop free from weeds and ensure healthy growth of the plant.

3.5 Selfing of flower

Sunflower is highly cross-pollinated crop. In this crop, the cross pollination occurs due to protandry. Cross pollination occurs mainly through insects (*Entomophily*) and to a limited extent by wind (Anemophily). Opening of flower starts from outer side of the head and proceeds towards center. The head takes 5-10 days for complete blooming depend on size of head and season. Anthesis occurs between 5 to 8 a.m. Pollen remains viable for 12 hours. Stigma remains receptive for 2-3 days.

3.6 Harvesting and threshing

Matured heads of sunflower were collected from the field and carried to the threshing floor and dried under the sun for 2-3 days. Threshing was done by beating with a piece of wood or a bamboo stick. Seeds were dried under the sun for 4-5 days and then stored in air tight containers.

3.7 Data recording

Collection of data on the following parameters were recorded from the sample plants during the course of experiment. The sampling was done from randomly selected 10 plants in each plot. The data were recorded from the following parameters:

1) Days to 50% flowering (DF 50%):

The days to 50% flowering were calculated from the date of sowing to approximately 50% of the flower buds per plot bloomed in each entry.

2) Days to maturity (DM):

It was estimated from the date of sowing following back of the disk turn yellow and bracts were turn brownish in color.

3) Plant height (PH cm):

At the full development of crop, 10 plants were selected randomly and height was recorded from the ground level to the point of the attachment of disk with the stem.

4) Head diameter (HD cm):

Head diameter in centimeter of randomly selected plants was measured from one edge of the head to the other.

5) Stem diameter (SD cm):

Stem diameter was measured from the same randomly selected plants per plot with a slide calipers by taking the reading in the cervical region of each plant at maturity.

6) Number of seeds/head:

Individually harvested, dried and threshed heads of some selected plants were subjected to count seeds per head. The fully matured ripen filled achenes were considered as seed whereas shrunken, partially filled and damaged achenes were considered as non-seed.

7) Seed weight/head (g):

The weight of seeds per head was recorded from the selected plants in grams on electric balance.

8) 1000 seed weight (g):

From each genotype, 1000 seeds were counted from random sample and weighed using an electrical balance in gram.

9) % Oil content:

The oil content of the oven-dried seeds was determined.

10) Yield/plot (g):

The yield data was calculated at 8% moisture level on plot basis.

3.8 Data analysis

Data obtained for yield contributing characters and yield was analyzed to find out the differences among the genotypes. The mean values of all the characters of 21 entries were evaluated. Correlation coefficient, path co-efficient analysis and cluster analysis were performed. All the analysis was performed by R Software.

CHAPTER IV

RESULTS AND DISCUSSION

The improvement of sunflower germplasm heavily depends upon the nature and extent of variability and also on the magnitude of inter-relationship of yield and its major contributing characters. Study of the true relationship between yield and its related traits helps to reveal their importance in selecting sunflower germplasms. The present study was carried out with a view to characterizing the sunflower germplasm and calculating the correlation and path coefficient for seed yield and yield contributing characters. The data were taken on different characters such as days to 50% flowering, days to maturity, plant height (cm), head diameter (cm), stem diameter (cm), number of seeds /head, 1000 seed weight (g) and plot yield (g). The obtained results of the current experiment are discussed in the following paragraphs:

4.1. Mean performance of sunflower accessions

4.2. Variability of quantitative morphological characters

4.3. Correlation coefficient analysis

4.4. Path coefficient analysis

4.5. Cluster analysis

4.1. Mean performance of sunflower accessions

The data regarding mean performance of sunflower genotypes is given in Table-**4.1**. The ranges for days to 50% flowering, days to maturity, plant height (cm), stem diameter (cm), head diameter (cm), number of seeds/ head, seed yield/head (g) ,1000 seed weight (g), % oil content and plot yield (g) were 64-93, 92-137, 72.8-160.4 cm, 0.96-2.22 cm, 7.2-16.6 cm, 19-303, 1.2-18.8 , 25-80g ,37.20-40.33% and 49-525.2 g, respectively (**Table-4.1.a &4.1.b**). The result revealed that genotype **ORCGP-21** took long time for days to 50% flowering (93 days), while **ORCGP-15** took lesser time for days to 50% flowering (64 days) as compared to the rest of the genotypes. In case of days to maturity, the genotype **ORCGP-21** took maximum days (137 days); however, the minimum days (92 days) were recorded in **ORCGP-15** genotype. With regard to plant height, the genotype **ORCGP-21** produced taller plants of 160.4 cm, while short stature plants of 72.8 cm were observed in the genotype **ORCGP-3.** This result was similar to Terzic *et al*., (2006) who obtained high variability in plant height. Onemli and Gucer (2010) found significant differences in plant height, head diameter, and period of flowering of sunflower wild genotypes. Highly significant differences were also reported in plant height, days to flowering and days to maturity in sunflower by Siddiqi *et al*., (2012).

Table 4.1. a. Performance of Sunflower Accessions for different morphological trait

Genotype	DF	DM	PH (cm)	SD (cm)	HD (cm)
ORCGP-1	72	104	82.2	1.34	9.2
ORCGP-2	67	101	83.4	1.08	10
ORCGP-3	72	110	72.8	0.96	7.4
ORCGP-4	74	105	87.8	1.76	9.8
ORCGP-5	70	99	73.6	1.06	7.2
ORCGP-6	74	107	116.8	1.40	11.4
ORCGP-7	88	109	119.6	1.70	11
ORCGP-8	77	109	103.8	2.02	16.6
ORCGP-9	75	109	82.2	1.50	7.4
ORCGP-10	78	100	99.6	1.68	10.4
ORCGP-11	75	103	108.8	1.68	10.2
ORCGP-12	81	110	101	1.84	14.8
ORCGP-13	70	102	107.8	1.68	14.4
ORCGP-14	65	95	74.8	1.28	14
ORCGP-15	64	92	90.4	1.42	13
ORCGP-16	66	99	101.6	1.50	13.6
ORCGP-17	70	101	81.2	1.36	12.4
ORCGP-18	65	101	77	1.60	13.4
ORCGP-19	68	107	94.6	1.56	9.6
ORCGP-20	72	125	46	1.23	8.7
ORCGP-21	93	137	160.4	2.22	15
Minimum	64	92	72.8	0.96	7.2
Maximum	93	137	160.4	2.22	16.6
± SE	1.61	2.15	5.79	0.07	0.65

DF: Days to 50% flowering; **DM:** Days to Maturity; **PH:** Plant height (cm); **SD**: Stem Diameter (cm); **HD:** Head diameter (cm)

Table 4.1.b. Performance of Sunflower Accessions for different morphological traits

Genotype	SH	YH (g)	SW (g)	% OC	PY(g)
ORCGP-1	186	5.4	50	39.470	235.4
ORCGP-2	114	10.8	80	40.100	209.8
ORCGP-3	75	3.5	60	39.000	153.5
ORCGP-4	100	5.2	55	37.775	235.2
ORCGP-5	20	2.6	60	39.725	92.6
ORCGP-6	303	14.6	50	39.379	379.6
ORCGP-7	162	14.8	55	39.400	294.8
ORCGP-8	194	16.4	75	38.850	211.40
ORCGP-9	104	3.6	50	38.875	118.60
ORCGP-10	108	8.2	65	38.875	333.20
ORCGP-11	137	10.6	65	38.200	495.60
ORCGP-12	164	10.4	50	38.675	360.40
ORCGP-13	284	18.8	80	38.725	213.80
ORCGP-14	153	11.2	75	38.725	291.20
ORCGP-15	147	8.8	65	40.325	153.80
ORCGP-16	19	1.2	60	38.575	351.20
ORCGP-17	198	12.6	50	39.725	147.00
ORCGP-18	58	4.4	25	38.775	109.40
ORCGP-19	112	7.2	50	38.500	172.20
ORCGP-20	94.7	4.3	47	37.200	49.00
ORCGP-21	232	11	35	39.99	525.20
Minimum	19	1.2	25	37.20	49.0
Maximum	303	18.8	80	40.33	525.2
± SE	18.26	1.18	3.42	0.19	31.03

SH: No. of seed/head; **SW:** 1000 Seed weight (g)**; OC%:** Oil content %; **PY**: Plot Yield (g)

For the trait of stem diameter, **ORCGP-21** produced thicker stems of 2.22 cm, while thinner stems of 0.96 cm were observed in the genotype **ORCGP-3**. For the trait of head diameter, **ORCGP-8** produced wider heads of 16.6 cm, while narrower heads of 7.2 cm were observed in the genotype **ORCGP-5**. With respect to number of seeds/head, **ORCGP-6** genotype produced more seeds/ head (303 seeds), whereas the genotype **ORCGP-16** set low number of seeds/ head (19 seeds) as compared to other genotypes. The genotype **ORCGP-13** gave higher yield/head (18.8g), however, the genotype **ORCGP-16** gave the lower yield/head (1.2 g). The genotype **ORCGP-2** and **ORCGP-13** produced maximum 1000 seed weight (80g), whereas the genotype

ORCGP-18 gave minimum 1000 seed weight (25 g). Data regarding oil percentage presented in Table 3 indicated that oil percentage was differed significantly by different genotypes. Maximum oil content value 40.325% was observed in **ORCGP-15** followed by **ORCGP-2** which gave 40.10% oil content but these two differed significantly from all other lines. Minimum oil contents 37.20% was observed in **ORCGP-20** genotype. These differences may be due to its superiority over other genotypes. Moreover, for the trait of plot yield ,the genotype **ORCGP-21** produced maximum yield (525.2g), while the genotype **ORCGP-20** produced minimum yield (49.0g). Accessions which have high 1000 seed weight and oil content are categorized as potential accessions because 1000 seed weight is one of the yield components (Dehkhoda *et al.*,2013 and Ion *et al*., 2015).

4.2. Variability of quantitative morphological characters

The values for average, standard deviation and coefficient of variation for all tested traits are given in Table 2. According to Smith *et al*., (1991) the evaluation and characterization of morphological traits are the first and basic step in description of germplasm. In some crop species like garlic (Panthee *et al*., 2006), melon (Lotti *et al*., 2008) and sunflower (Kholghi *et al*., 2011), morphological statistics has been used for determining the variability. Variability in sunflower accessions for quantitative morphological traits had also been reported by many researchers (Sujatha *et al*., 2002; Nehru and Manjunath 2003; Ozer *et al*., 2003; Rao *et al*. , 2003).

Twenty one sunflower genotypes were evaluated and Table 2 shows the variability of quantitative morphological characters. All the ten quantitative characters used in the present study showed a great deal of variability among the studied material which is revealed by the coefficient of variation (CV %) and their average values (Table 2). The coefficient of variation

(CV%) for days to 50% flowering, days to maturity, plant height (cm), stem diameter (cm), head diameter (cm), number of seeds/ head, seed yield/head (g) ,1000 seed weight (g),% oil content and plot yield (g) were 10.09%, 9.29%, 27.73%, 20.62%, 26.12%, 58.54%, 60.22%, 27.54%, 2.23%, and 57.26%, respectively. The highest CV% was recorded for the character seed yield/head (60.22g) followed by the character number of seeds/head (58.54) and plot yield (57.26g). Tan and Tan (2011) also reported that the morphological variation on the observed characters was found highly variable for some characters. The lowest CV% was observed for the characters % oil content (2.23) followed by the character days to maturity (9.29) and days to 50% flowering (10.09) (Table 2).

Table 4.2: Variability of quantitative morphological characters of sunflower accessions

Characters	Initial	Mean	Stand Dev	CV%
Days to 50% flowering	DF	73	7.38	10.09
Days to maturity	DM	105	9.84	9.29
Plant height (cm)	PH	95.59	26.51	27.73
Stem diameter (cm)	SD	1.52	0.31	20.62
Head diameter (cm)	HD	11.44	2.98	26.12
No. Seeds /head	SH	142.86	83.63	58.54
Yield/head (g)	YH	8.94	5.38	60.22
1000 seed weight (g)	SW	56.82	15.64	27.54
% oil content	% OC	38.37	0.87	2.23
Plot Yield (g)	PY	248.13	142.10	57.26

According to Hadi *et al*., (2014), the variability is low when CV varied from 0 to 25%. From this study, only three characters such as % oil content, days to maturity and days to 50% flowering showed low variability. The low variability for these traits emphasizes the need for generating higher variability. Except the three characters, the high variability was observed for quantitative characters for all accessions (Table 4.2). Chmeleva *et al.*, (1981) found oil content in the range of 34.9 to 64.3% while Andrei (1997) found plant height in the range of 131 to 158 cm and oil content from 48.6 to 52.5% in sunflower hybrids. Presotto *et al*., (2009) reported that the populations of *Helianthus annuus* naturalized in Argentina presented a high degree of phenotypic variability.

4.3. Correlation coefficient analysis

Correlation coefficients are useful since it allows to determine the component character on which selection can be based, thus improves seed yield (Jockovic *et al*., 2012). Correlation coefficient determines the closeness of two important variables so that selection criteria could be reliably established. For the simultaneous improvement of traits in sunflower, Mogali and Virupakshappa (1994) studied the association of seed yield with yield related traits. In the present study, both positive and negative correlations were found between different traits (Table 4.3). Greater positive association observed for most of the characters indicated that these characters could be simultaneously improved and further recommend that increase in any one would lead to improvement of other characters.

Table 4.3. Phenotypic correlations among different characteristics of 21 sunflower accessions

Characters	DF	DM	PH	SD	HD	SH	YH	SW	% OC	PY
DF	1	0.71**	0.68**	0.64**	0.14^{ns}	0.35*	0.31*	-0.27 ^{ns}	0.07 ^{ns}	0.55**
DM		1	0.36*	0.41 ^{ns}	0.03 ^{ns}	0.23*	0.03 ^{ns}	-0.47*	-0.17 ^{ns}	0.24*
PH			1	0.74**	0.50*	0.54**	0.51**	-0.08 ^{ns}	0.34 ^{ns}	0.80**
SD				1	0.64**	0.39 **	0.41**	-0.21 ^{ns}	-0.11 ^{ns}	0.56**
HD					1	0.46**	0.58**	0.09 ^{ns}	0.12 ^{ns}	0.40**
SH						1	0.84**	0.11 ^{ns}	0.25 ^{ns}	0.39**
YH							1	0.39 ^{ns}	0.23 ^{ns}	0.34**
SW								1	0.08 ^{ns}	0.02 ^{ns}
% OC									1	0.08 ^{ns}
PY										1

Note: * significant at $p \leq 0.05$, ** significant at $p \leq 0.01$

DF= Days to 50% flowering
DM= Days to maturity
PH= Plant height (cm)
SD= Stem diameter (cm)
HD= Head diameter (cm)
SH= No. Seed /head
YH= Yield/head (g)
SW= 1000 seed weight (g)
%OC= % oil content
PY= Plot yield (g)

4.3.1 Days to 50% flowering

Days to 50% flowering exhibited highly significant and positive correlation with days to maturity, plant height, stem diameter, plot yield suggested that if days to 50% flowering increased then days to maturity, plant height, stem diameter and plot yield will be increased (Table 4.3). On the contrary, the correlations between the days to 50% flowering with head diameter, 1000 seed weight and % oil content were negative. Days to 50% flowering showed negative and significant correlation with head diameter and seed weight reported by (Sujatha and Nadaf, 2013).

Manivannan *et al*., (2005) reported that days to 50% flowering had a significantly positive association with head diameter and a significant negative association with oil contents. The negative correlation between these two characteristics can be explained that as soon as flower initiation begins head will have more time to accumulate nutrients and grow until the end of physiological maturity. Development of inbred lines with earlier flowering period would be important because such heads will have more time for seed filling.

4.3.2. Days to maturity

Correlations between days to maturity and the traits plant height, number of seed/head and plot yield score were found positive but stem diameter, head diameter, yield/head and % oil content were negative. Our results are in agreement with the results of Khan *et al*. (1992) who also found positive phenotypic and genotypic correlations between days to maturity and achene yield.

4.3.3. Plant height

Plant height showed positive and highly significant correlation with stem diameter, number of seeds /head, yield / head and plot yield. Plant height was positively correlated with head diameter which was reported by Chikkadeviah *et al*., (2002) and Tahir *et al*., (2002). It is suggested that with increasing plant height, stem diameter at base also increased to support larger heads with more number of seed/ head which will prevent tall plants from lodging.

4.3.4. Head diameter

Head diameter showed positive and highly significant correlation with number of seed/head, yield/head and plot yield but negative correlation with 1000 seed weight and % oil content.Head diameter had considerable effect on seed yield reported by Ahmad *et al*,(1991);Mogali and Virupakshappa (1994) and Darvishzadeh *et al*.,(2011) studies. Head diameter affects the number of flowers and seeds per head. Larger heads accommodate more number of seeds and possibly larger seed size. But too large head size increases the risk of lodging. Head diameter exerted non-significant positive correlation with 1000-seed weight. Ozer (2003) reported that the correlation between head diameter and 1000 seed weight was insignificant.

4.3.5. Stem diameter

Stem diameter showed positive and highly significant correlation with head diameter, number of seeds/head, yield/head and plot yield. Amin *et al.*, (2016) also found positive correlation between head diameter with stem diameter.

4.3.6. No of seed/head

No. seed/ head showed positive and highly significant correlation with yield/head and plot yield but negative correlation with 1000 seed weight and % oil content. Similarly, Singh (2010) found negative non-significant correlation between number of seed per head and seed weight.

4.3.7. 1000 seed weight

1000 seed weight showed negative correlation with % oil content. The similar result was also reported by Joksimović *et al*., (2004), Kaya *et al*., (2007) and Mijić *et al*., (2009).

4.3.8. % oil content

The correlations were found non-significant between % oil content and all the phenotypic traits such as days to 50% flowering (0.07), days to maturity (-0.17), plant height (0.34), stem diameter (-0.11), head diameter (0.12), no. seed/head (0.25), yield/head (0.23) and 1000 seed weight (0.08). Negative association between seed yield and oil content was reported by Vidhyavathi *et al*., (2005), Habib *et al*., (2007) and Arshad *et al*., (2010) also reported that seed yield expressed negative and highly significant genotypic and phenotypic association with oil content.

4.3.9. Yield

Plot yield showed highly significant and positive association with days to flowering, plant height, stem diameter, head diameter, number of seeds per head and yield per head. The investigations of many authors showed that there is a positive correlation between the yield and some morphological and agricultural characters such as plant height, head diameter, seed number per plant and 1000-seed weight (El-Ahmer et al., 1989;; Mogali and Virupakshappa, 1994; El-Hosary et al., 1999; Naderi A., 1998; Narayana et al., 1998).This indicates that strong association of these characters with plot yield could be fruitfully exploited for enhancing the yield potential in sunflower. So, selection of these characters for plot yield would be useful in selecting superior sunflower genotypes. Similar results were also reported by Dhaduk *et al*., (1985), Murthy and Shambulingappa (1989), Singh and Labana (1990), Marinkovic (1992), Mogali and Virupakshappa (1994), Nehru and Manjunath (2003) and Prasad *et al*., (2006).

4.4. Path coefficient analysis

Path coefficient analysis is a suitable technique that separates the phenotypic correlation coefficients into its direct and indirect effects so that the contribution of each trait to yield and yield contributing characters can be easily estimated. The path coefficient analysis being a more precise method partitions the direct and indirect effects of independent variables on the dependent variable. Therefore, the path analysis explains the clear impact of independent variables on the dependent one. This method has been extensively used by the sunflower researchers (Yasin and Singh, 2010; Darvishzadeh *et al*., 2011; Kholghi *et al*., 2011; Pandya *et al*., 2016).

Punia and gill (1994); Kaya and Atakisi (2003); Shankar *et al*. (2006) and Darvishzadeh *et al.* (2011), comparing simple correlation coefficient and path-coefficient analyses, concluded that path-coefficient analyses provided more information about direct and indirect effetcs of the examined characteristics on seed yield per plant. Yasin and Singh (2010) also concluded that path-coefficient is helpful in partitioning the correlation into direct and indirect effects. In this way, relative contribution of each component character to the yield can be assessed. In other words, path analysis measures direct and indirect contribution of various independent characters to a dependent character. Using path-coefficient analysis, it is easy to determine which yield component is influencing the yield substantially. Therefore, the direct and indirect effects of nine characters on seed yield of sunflower are given in Table 4.4.

Path analysis revealed that the character plant height had the maximum direct effect (1.146) on seed yield per plant whereas some other characters showed medium to low positive direct effect on seed yield. Positive direct effects on seed yield per plant were exhibited by days to flowering, head diameter and number of seeds/head (0.558, 0.437 and 0.369, respectively). So, these traits were considered important to increase yield of sunflower. Similar results were also reported by Ahmad *et al*.,(1991) for plant height, days to physiological maturity and oil content; Marinković(1992) for 1000-seed weight and number of seeds/head; Arshad *et a*l., (2007) for days to flowering, plant height and head diameter; Machikowa and Saetang (2008) for head diameter and plant height; Yasin and Singh (2010) and Kholghi *et al*., (2011) for number of seeds/head, 1000-seed weight and head diameter and Darvishzadeh *et al*., (2011) for head diameter. Marinković (1992) and Behradfar *et al*., (2009) reported positive direct effects of the weight of 1000 seeds and total seed number per head on seed yield of sunflower.

Table 4.4. Direct and indirect effects of different characteristics on seed yield of sunflower accessions

Characters	DF	DM	PH	SD	HD	SH	YH	SW	% OC	Correlation
DF	**0.558**	-0.275	0.779	-0.431	0.061	0.129	-0.197	-0.039	-0.034	0.55**
DM	0.396	**-0.387**	0.412	-0.276	0.013	0.084	0.019	-0.068	0.084	0.24*
PH	0.379	-0.139	**1.146**	-0.498	0.218	0.199	-0.324	-0.011	-0.169	0.80**
SD	0.357	-0.158	0.848	**-0.673**	0.279	0.144	-0.260	-0.030	0.054	0.56**
HD	0.078	-0.011	0.573	-0.431	**0.437**	0.169	-0.368	0.013	-0.059	0.40**
SH	0.195	-0.089	0.619	-0.262	0.201	**0.369**	-0.534	0.016	-0.124	0.39**
YH	0.173	-0.011	0.584	-0.276	0.253	0.310	**-0.636**	0.057	-0.114	0.34**
SW	-0.150	0.182	-0.091	0.141	0.039	0.040	-0.248	**0.146**	-0.039	0.02 ^{ns}
% OC	0.039	0.065	0.389	0.074	0.052	0.092	-0.146	0.011	**-0.499**	0.08 ^{ns}

Bold: Direct effect, Normal: Indirect effect
**** Significance at 0.01 probability level *Significance at 0.05 probability level**

Patil *et al*., (1996) reported significant positive direct effects of 100-seed weight on sunflower seed yield. The direct effect of other character on seed yield such as 1000 seed weight was positive but quite low (0.146). On the other hand, the direct effect on seed yield of days to maturity, stem diameter, yield/head and % oil content were negative (-0.387,-0.673,-0.636 and -0.499, respectively).Habib *et al*., (2007) also reported similar results in their respective study. It is evident from this association that decrease in flowering period may increase oil content ultimately. Negative indirect effect of oil content with seed number per head and 1000-seed weight revealed that identifying a trait as an indirect selection criterion based only on positive direct effect and disregarding the nature and magnitude of correlation of that trait with oil yield would be misleading (Darvishzadeh *et al*., 2011).

4.5. Cluster analysis

Hierarchical clustering indicates the level of variability among the lines and this information can be efficiently used in superior line selection (Sultana *et al.*, 2006). It is generally believed that a superior variety could be developed by combining the two genetically distant parents (Nasreen *et al.*, 2011). Thus cluster analysis provided useful information about the variability of the lines under study (Nasreen *et al.*, 2011). The inbred lines that show a considerable genetic distance, coupled with superior performance for economically important traits like seed yield and its controlling characters, may be used in sunflower hybrid/varietal improvement program (Nasreen *et al.*, 2011).

The association among different accessions is presented in the form of dendrogram (Fig. 3) prepared using R software. From the Fig. 3, most of the accessions were included in cluster V and I (6 and 5 accessions) followed by cluster III (4 accessions) and cluster II and IV contains only three accessions. The accessions, which are lying nearer to each other in the dendrogram are more similar to one another than those lying away from each other. The present dendrogram shows the relatively high magnitude of resemblance among the sunflower accessions in different clusters. Interestingly, the accession **ORCGP-16** showed the extreme place from **ORCGP-9** meaning thereby that they had maximum genetic distance between them.

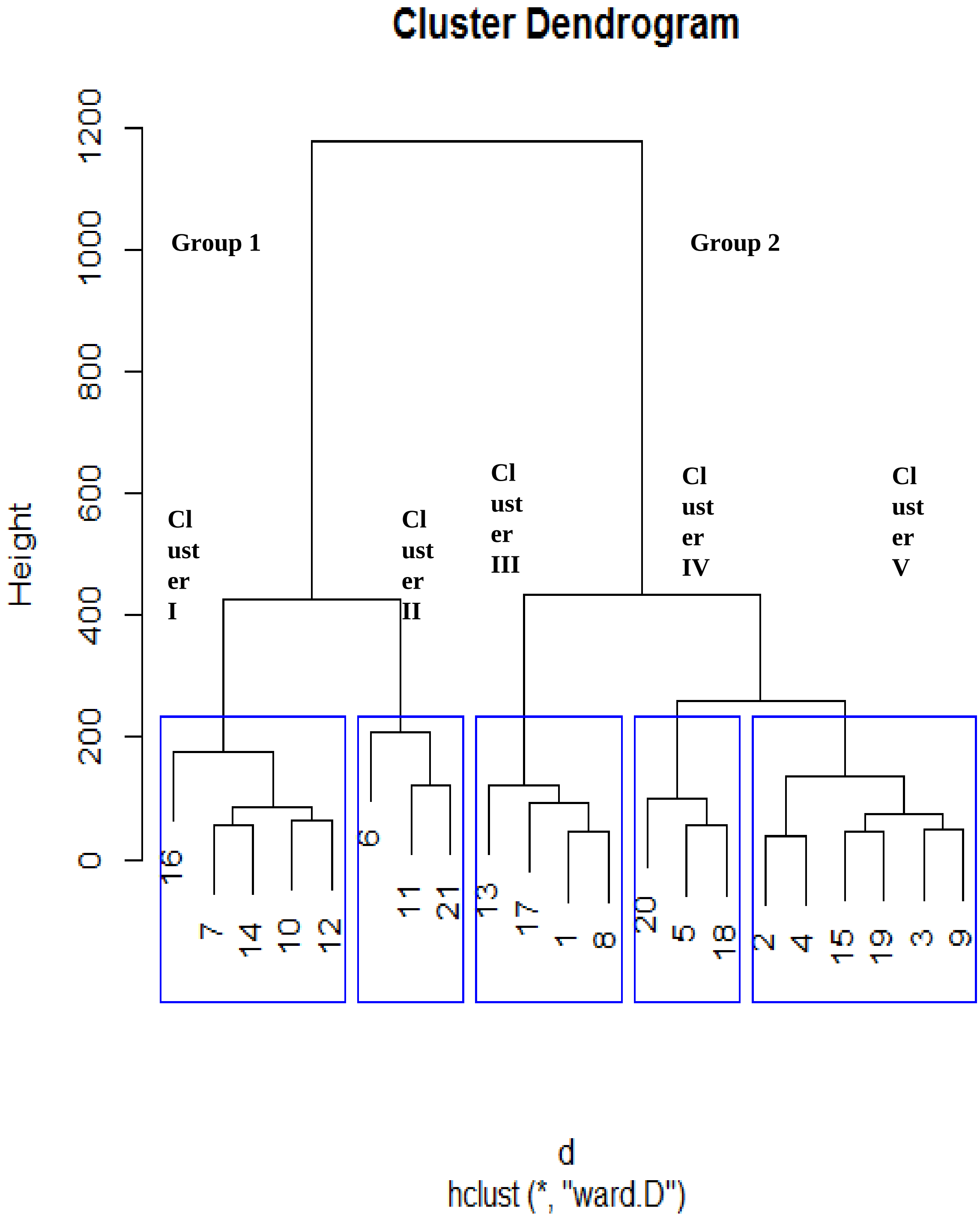

Fig. 4.1. Cluster Dendrogram of 21 sunflower accessions used for morphological analysis

Cluster analysis indicates the extent of diversity in the material that could be used as parental lines in future variety development program (Sultana and Ghafoor 2008). Based on quantitative traits, all sunflower accessions by cluster analysis were divided into 2 main groups (Table 6). The first main group is divided into two subgroups (**I and II**). The first subgroup **(I)** consists of five genotypes (ORCGP-16, ORCGP-7, ORCGP-14, ORCGP-10, ORCGP-12), while in the second subgroup **(II)** there are three genotypes (ORCGP-6, ORCGP-11, ORCGP-21). The second main group is divided into three subgroups **(III, IV and V**). The first subgroup **(III)** consists of three genotypes (ORCGP-13, ORCGP-17, ORCGP-18), the second subgroup (**IV**) consists of three genotypes (ORCGP-20, ORCGP-5, ORCGP-18) and the third subgroup (**V)** consists of six genotypes (ORCGP-2, ORCGP-4, ORCGP-15, ORCGP-19, ORCGP-3 and ORCGP-9).

Table 4.5. Grouping of sunflower accessions based on morphological analysis

Cluster	Sub-Group	Accessions	No. of Genotypes
1	I	ORCGP-16, ORCGP-7, ORCGP-14, ORCGP-10, ORCGP-12	5
	II	ORCGP-6, ORCGP-11, ORCGP-21	3
2	III	ORCGP-13, ORCGP-17, ORCGP-1, ORCGP-8	4
	IV	ORCGP-20, ORCGP-5, ORCGP-18	3
	V	ORCGP-2, ORCGP-4, ORCGP-15, ORCGP-19, ORCGP-3, ORCGP-9	6

As the selection is valuable for those characters having high variability, the lower variability coefficients indicated that there was less variation for those traits in the material evaluated. In this study, none of the accession was found to be promising for all the nine quantitative characters studied. However, some accessions identified as promising for different traits (Table 7). The selection based on days to 50% flowering, days to maturity, plant height, number of seed/head and yield/plot would be more productive. Such accessions were very useful as a base population to develop promising populations and lines in future. In this study, six out of 21 accessions were found took less than 70 days to 50% flowering (ORCGP-2, ORCGP-14, ORCGP-15, ORCGP-16, ORCGP-18, ORCGP-19) and four accessions took below 100 days to mature (ORCGP-5, ORCGP-14, ORCGP-15, and ORCGP-16). These accessions could be used to develop early maturing sunflower variety.13 accessions (ORCGP-1, ORCGP-2, ORCGP-3, ORCGP-4, ORCGP-5, ORCGP-9, ORCGP-11, ORCGP-14, ORCGP-15, ORCGP-17, ORCGP-18, ORCGP-19, and ORCGP-20) were evaluated as short stature plants with the height of below 100 cm. These accessions could be suitable parental line to develop dwarf sunflower variety specially for cultivating in the windy area. Above 150 seeds per head was observed in ten accessions (ORCGP-1, ORCGP-6, ORCGP-7, ORCGP-8, ORCGP12, ORCGP-13, ORCGP-14, ORCGP-15, ORCGP-1, ORCGP-21). High yielding genotypes (>350g per plot yield)was observed in six accessions (ORCGP-6, ORCGP-10, ORCGP-11, ORCGP-12, ORCGP-16, ORCGP-21) which might be used as parental line to develop high yielding sunflower variety.

Table 4.6. Promising accessions of sunflower for different characters

Characters	**Germplasm accessions**
Days to 50% flowering (<70 days)	ORCGP-2, ORCGP-14, ORCGP-15, ORCGP-16, ORCGP-18, ORCGP-19.
Days to maturity (< 100 days)	ORCGP-5, ORCGP-14, ORCGP-15, ORCGP-16.
Plant height (<100 cm)	ORCGP-1, ORCGP-2, ORCGP-3, ORCGP-4, ORCGP-5, ORCGP-9, ORCGP-11, ORCGP-14, ORCGP-15, ORCGP-17, ORCGP-18, ORCGP-19, ORCGP-20.
Number of seed/head (>150)	ORCGP-1, ORCGP-6, ORCGP-7, ORCGP-8, ORCGP12, ORCGP-13, ORCGP-14, ORCGP-15, ORCGP-1, ORCGP-21.
Yield/plot (>350g)	ORCGP-6, ORCGP-10, ORCGP-11, ORCGP-12, ORCGP-16, ORCGP-21.

Besides quantitative traits, wide variability was also observed for some qualitative traits. As sown in Figure 4, the sunflower accessions show variability in size and shape of leaves (Fig 4A &4B), in different size and shape of head (Fig 4C &4D), and different size, shape and color of both ray and disc floret (Fig 4E &4F). Different size leaf in sunflower was reported by Atlagic and Skoric (1999) while different shape leaf in sunflower was reported by Terzic *et al.* (2006). Atlagic and Skoric (1999) reported a larger head diameter in the sunflower F1 hybrids. Dudhe (2012) reported elongated type ray floret in sunflower F1 hybrids.

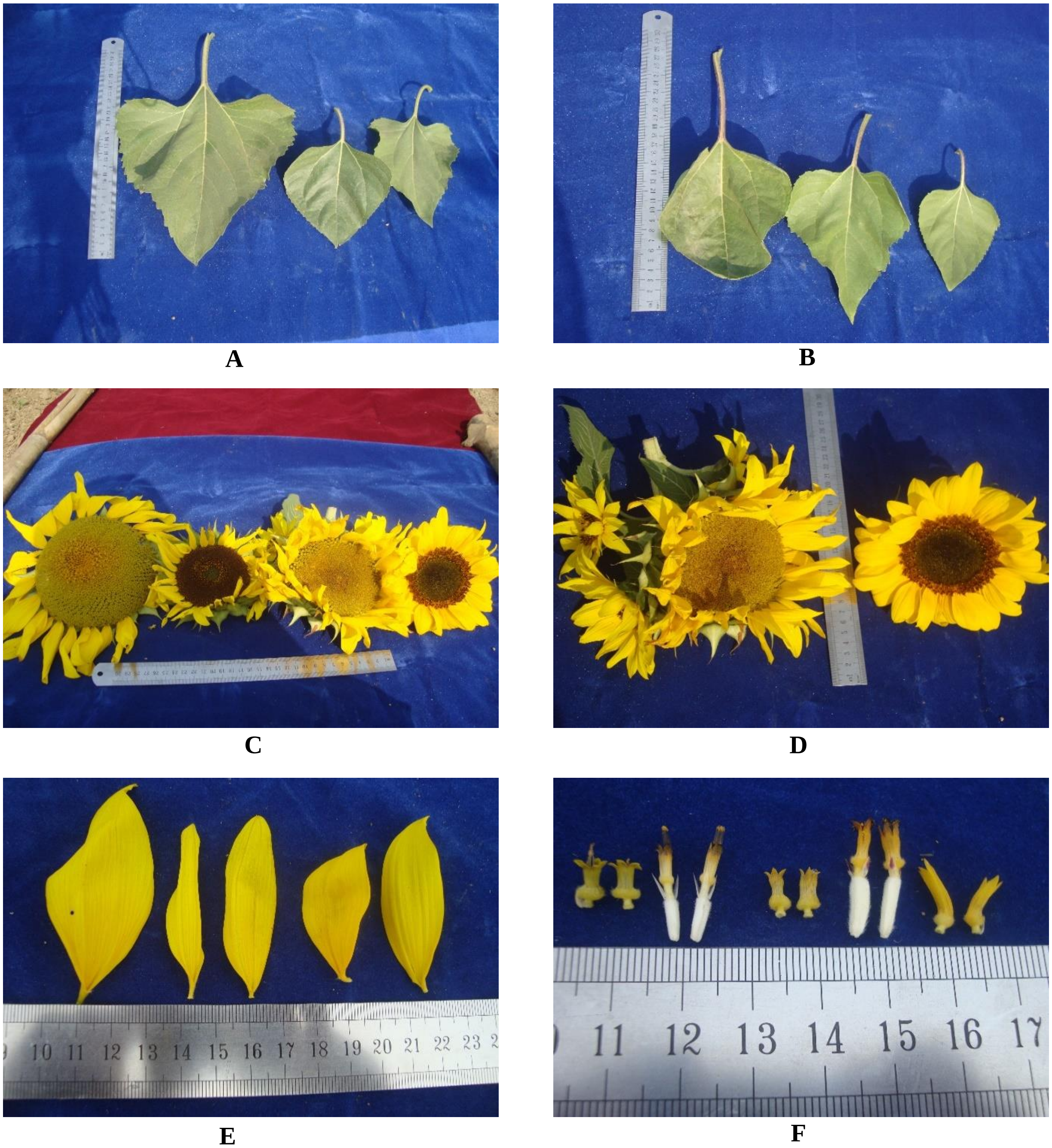

Figure 4.2: Variability of some qualitative traits in sunflower: (A) size of leaves,(B) shape of leaves,(C)size of head ,(D) shape of head ,(E) size, shape and color ray floret and (F) size, shape and color disc floret.

CHAPTER V

SUMMARY, CONCLUSION AND RECOMMENDATION

SUMMARY

In this present study, twenty-one sunflower genotypes were evaluated for yield and yield contributing characters under field condition in research field of Oilseed Research Centre (ORC), Bangladesh Agricultural Research Institute (BARI), Gazipur, Dhaka during the period from November 2018 to March 2019. The objectives of this study were characterizing the sunflower germplasm according to their yield contributing characters, estimating association among yield and yield related traits and partitioning the correlation coefficients into direct and indirect effects and identifying high yielding, short duration and dwarf sunflower genotypes. Data on yield attributing traits such as days to 50% flowering, days to maturity, plant height (cm), head diameter (cm),stem diameter (cm),number of seed/ head, 1000 seed weight (g) and plot yield (g) were taken. The mean performance of sunflower genotypes showed the presence of significant differences among the tested genotypes for all characters considered, indicating the existence of variability among the tested genotypes. The maximum days to 50% flowering were recorded (93 days) in **ORCGP-21** and minimum (64 days) was observed in **ORCGP-15.** The lowest day to maturity (92 days) was scored in**ORCGP-15** and the maximum day to maturity (137 days) was noted in **ORCGP-21.** The minimum plant height (72.8cm) was recorded in **ORCGP-3**and the maximum plant height (160.4 cm) was scored by **ORCGP-21.** The genotype **ORCGP-21** produced thicker stems of 2.22 cm, while thinner stems of 0.96 cm were observed in the genotype **ORCGP-3**. **ORCGP-8** produced wider heads of 16.6 cm, while narrower heads of 7.2 cm were observed in the genotype **ORCGP-5**. The highest number of seeds/head(303 seeds) was recorded in **ORCGP-6,** whereas the minimum number of seeds/head (19 seeds) was observed in

ORCGP-16. The genotype **ORCGP-13** gave higher yield/head (18.8g) but the genotype **ORCGP-16** gave the lower yield/head (1.2 g). The maximum seed weight (80g) was observed in the genotype **ORCGP-2** and the genotype **ORCGP-13** and minimum seed weight (25 g) was observed in the genotype **ORCGP-18.** The highest plot yield (525.2g) was recorded in the genotype **ORCGP-21** whereas the lowest plot yield (49.0g) was observed in the genotype **ORCGP-20.**

Genetic variability in sunflower accessions for morphological traits is the first and basic step in evaluation of germplasm.The coefficient of variation (CV) for days to 50% flowering, days to maturity, plant height (cm), stem diameter (cm), head diameter (cm), number of seeds/ head, seed yield/head (g),1000 seed weight(g),% oil content and plot yield were 10.09%, 9.29%, 27.73%, 20.62%, 26.12%, 58.54%, 60.22%, 27.54%, 2.23%, and 57.26% respectively. The highest CV% was recorded for the character seed yield/head (60.22g) followed by number of seeds/head (58.54) and plot yield (57.26).

Correlation coefficient determines the closeness of two important variables so that selection criteria could be reliably established. Plot yield was positively and highly significantly correlated with days to 50% flowering (0.55**), plant height (0.80**), stem diameter (0.56**), head diameter (0.40**), number of seeds per head (0.39**) and yield per head (0.34**). Days to 50% flowering had highly significant and positive correlation with days to maturity (0.71**), plant height (0.68**), stem diameter (0.64**), plot yield (0.55**).The correlations between the days to 50% flowering and number of seed/head (0.35*), yield/head (0.31*) were positive and significant. Days to maturity showed positive and significant correlation with plant height (0.36*), number of seed/head (0.23*) and plot yield (0.24*).

The path analysis revealed that the character plant height had the maximum direct effect (1.146) on seed yield per plant whereas all other characters showed low positive direct effect on seed yield. Positive direct effects on seed yield per plant were exhibited by days to flowering, head diameter and number of seeds/head were high (0.558, 0.437 and 0.369 respectively). Positive direct effects of these traits on plot yield indicated their importance in determining these complex traits and therefore, should be kept through practicing selection aimed at the improvement of plot yield. Days to 50% flowering and number of seeds/head also were the important contributors to yield per hectare which could be taken in consideration for selecting genotypes.

Cluster analysis indicates the extent of genetic diversity in the material that could be used as parental lines in variety development. Cluster analysis using R software classified the 21 sunflower populations into two main groups. A large number of accessions was placed in cluster V (6 accessions) followed by cluster I (5 accessions), cluster III (4 accessions) and cluster II and IV contains only three accessions. The maximum variability was observed between clusters I and cluster V which may give rise to very good cross combination.

CONCLUSION

Therefore, considering the mean performance, variability of quantitative morphological characters, correlation coefficient analysis, path coefficient analysis and cluster analysis, short duration genotypes are **ORCGP-14, ORCGP-15, ORCGP-16**and high-yielding genotypesare **ORCGP-6, ORCGP-10, ORCGP-11, ORCGP-12, ORCGP-16, ORCGP -21**. It indicates that the inclusion of these genotypes as potential germplasms for the development of superior sunflower cultivars. Plant height is an important character for sunflower genotypes as dwarf plant. Some dwarf genotypes are **ORCGP-1, ORCGP-2, ORCGP-3, ORCGP-4, ORCGP-5, ORCGP-9, ORCGP-11, ORCGP-14, ORCGP-15, ORCGP-17, ORCGP-18, ORCGP-19,** and **ORCGP-20.** Lastly, it can be concluded that no germplasm accession is found to be good for all the quantitative characters. However, different accessions have been identified as promising for different traits.

RECOMMENDATION

The selected promising genotypes could be used to develop sunflower variety.

CHAPTER VI

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APPENDICES

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3  72 110  72.8 0.96  7.4  75  3.5 60 39.00 153.5
4  74 105  87.8 1.76  9.8 100  5.2 55 37.78 235.2
5  70  99  73.6 1.06  7.2  20  2.6 60 39.73  92.6
6  74 107 116.8 1.40 11.4 303 14.6 50 39.38 379.6
7  88 109 119.6 1.70 11.0 162 14.8 55 39.40 294.8
8  77 109 103.8 2.02 16.6 194 16.4 75 38.85 211.4
9  75 109  82.2 1.50  7.4 104  3.6 50 38.88 118.6
10 78 100  99.6 1.68 10.4 108  8.2 65 38.88 333.2
11 75 103 108.8 1.68 10.2 137 10.6 65 38.20 495.6
12 81 110 101.0 1.84 14.8 164 10.4 50 38.68 360.4
13 70 102 107.8 1.68 14.4 284 18.8 80 38.73 213.8
14 65  95  74.8 1.28 14.0 153 11.2 75 38.73 291.2
15 64  92  90.4 1.42 13.0 147  8.8 65 40.33 153.8
16 66  99 101.6 1.50 13.6  19  1.2 60 38.58 351.2
17 70 101  81.2 1.36 12.4 198 12.6 50 39.73 147.0
18 65 101  77.0 1.60 13.4  58  4.4 25 38.78 109.4
19 68 107  94.6 1.56  9.6 112  7.2 50 38.50 172.2
20 72 125  46.0 1.23  8.7  95  4.3 47 37.20  49.0
21 93 137 160.4 2.22 15.0 232 11.0 35 39.99 525.2
> attach(X)
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df    dm  phcm  sdcm hdcm   sh  yhg    sw    OC   PY
df    1.00  0.71  0.68  0.64 0.14 0.35 0.31 -0.27  0.07 0.55
dm    0.71  1.00  0.36  0.41 0.03 0.23 0.03 -0.47 -0.17 0.24
phcm  0.68  0.36  1.00  0.74 0.50 0.54 0.51 -0.08  0.34 0.80
sdcm  0.64  0.41  0.74  1.00 0.64 0.39 0.41 -0.21 -0.11 0.56
hdcm  0.14  0.03  0.50  0.64 1.00 0.46 0.58  0.09  0.12 0.40
sh    0.35  0.23  0.54  0.39 0.46 1.00 0.84  0.11  0.25 0.39
yhg   0.31  0.03  0.51  0.41 0.58 0.84 1.00  0.39  0.23 0.34
sw   -0.27 -0.47 -0.08 -0.21 0.09 0.11 0.39  1.00  0.08 0.02
OC    0.07 -0.17  0.34 -0.11 0.12 0.25 0.23  0.08  1.00 0.08
PY    0.55  0.24  0.80  0.56 0.40 0.39 0.34  0.02  0.08 1.00

$pvalue
df           dm          phcm         sdcm        hdcm
df   1.0000000000 0.0002956738 6.383448e-04 0.0017224661 0.542392240
dm   0.0002956738 1.0000000000 1.097127e-01 0.0662251130 0.892102818
phcm 0.0006383448 0.1097126885 1.000000e+00 0.0001199703 0.021770547
sdcm 0.0017224661 0.0662251130 1.199703e-04 1.0000000000 0.001816575
hdcm 0.5423922402 0.8921028176 2.177055e-02 0.0018165752 1.000000000
sh   0.1167540600 0.3222729810 1.168611e-02 0.0839347689 0.035863071
yhg  0.1697113214 0.8966583881 1.774198e-02 0.0627553689 0.005747612
```

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sw   0.2390799082 0.0296008330 7.387802e-01 0.3619580555 0.703478014
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PY   0.0091297956 0.2906766627 1.168028e-05 0.0077966660 0.072429845
sh            yhg           sw         OC           PY
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dm   3.222730e-01 8.966584e-01 0.02960083 0.4556764 2.906767e-01
phcm 1.168611e-02 1.774198e-02 0.73878019 0.1342508 1.168028e-05
sdcm 8.393477e-02 6.275537e-02 0.36195806 0.6292897 7.796666e-03
hdcm 3.586307e-02 5.747612e-03 0.70347801 0.5976261 7.242985e-02
sh   1.000000e+00 2.098139e-06 0.63780376 0.2797890 8.137330e-02
yhg  2.098139e-06 1.000000e+00 0.07784827 0.3129402 1.261299e-01
sw   6.378038e-01 7.784827e-02 1.00000000 0.7419887 9.300912e-01
OC   2.797890e-01 3.129402e-01 0.74198865 1.0000000 7.318212e-01
PY   8.137330e-02 1.261299e-01 0.93009119 0.7318212 1.000000e+00

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[1] 21

>
```

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> W
df  dm  phcm sdcm hdcm  sh  yhg sw    OC    PY
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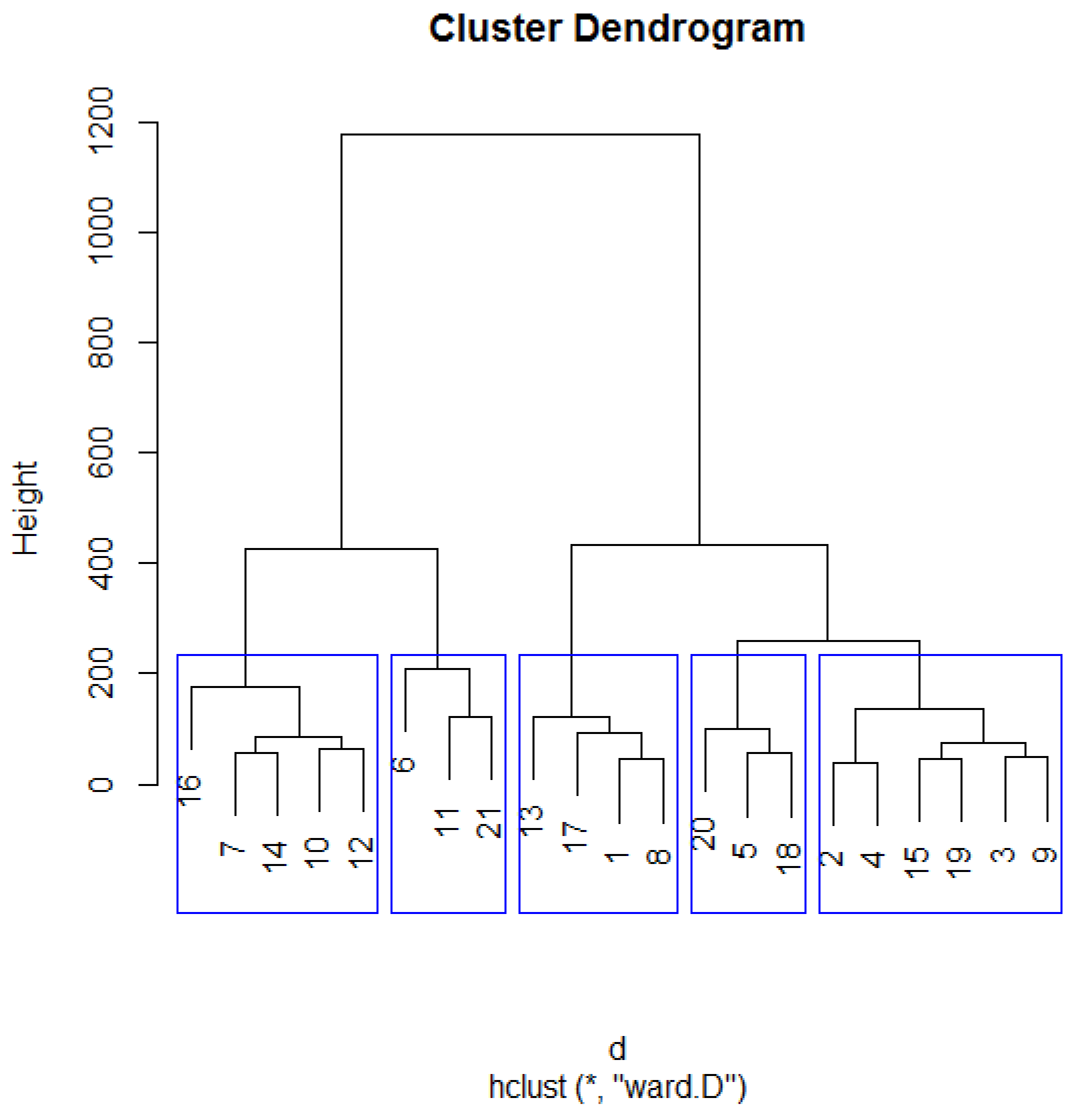
2  67 101  83.4 1.08 10.0 114 10.8 80 40.10 209.8
3  72 110  72.8 0.96  7.4  75  3.5 60 39.00 153.5
4  74 105  87.8 1.76  9.8 100  5.2 55 37.78 235.2
5  70  99  73.6 1.06  7.2  20  2.6 60 39.73  92.6
6  74 107 116.8 1.40 11.4 303 14.6 50 39.38 379.6
7  88 109 119.6 1.70 11.0 162 14.8 55 39.40 294.8
8  77 109 103.8 2.02 16.6 194 16.4 75 38.85 211.4
9  75 109  82.2 1.50  7.4 104  3.6 50 38.88 118.6
10 78 100  99.6 1.68 10.4 108  8.2 65 38.88 333.2
11 75 103 108.8 1.68 10.2 137 10.6 65 38.20 495.6
12 81 110 101.0 1.84 14.8 164 10.4 50 38.68 360.4
13 70 102 107.8 1.68 14.4 284 18.8 80 38.73 213.8
14 65  95  74.8 1.28 14.0 153 11.2 75 38.73 291.2
15 64  92  90.4 1.42 13.0 147  8.8 65 40.33 153.8
16 66  99 101.6 1.50 13.6  19  1.2 60 38.58 351.2
17 70 101  81.2 1.36 12.4 198 12.6 50 39.73 147.0
18 65 101  77.0 1.60 13.4  58  4.4 25 38.78 109.4
19 68 107  94.6 1.56  9.6 112  7.2 50 38.50 172.2
20 72 125  46.0 1.23  8.7  95  4.3 47 37.20  49.0
21 93 137 160.4 2.22 15.0 232 11.0 35 39.99 525.2
>library(agricolae)
> y=W$PY
> x=W[,c(1,2,3,4,5,6,7,8,9)]
> cor.y=correlation(y,x)$correlation
> cor.y
df   dm phcm sdcm hdcm   sh  yhg   sw   OC
y 0.55 0.24  0.8 0.56  0.4 0.39 0.34 0.02 0.08
> cor.x=correlation(x)$correlation
> cor.x
df    dm  phcm  sdcm hdcm   sh  yhg    sw    OC
df    1.00  0.71  0.68  0.64 0.14 0.35 0.31 -0.27  0.07
dm    0.71  1.00  0.36  0.41 0.03 0.23 0.03 -0.47 -0.17
phcm  0.68  0.36  1.00  0.74 0.50 0.54 0.51 -0.08  0.34
sdcm  0.64  0.41  0.74  1.00 0.64 0.39 0.41 -0.21 -0.11
hdcm  0.14  0.03  0.50  0.64 1.00 0.46 0.58  0.09  0.12
sh    0.35  0.23  0.54  0.39 0.46 1.00 0.84  0.11  0.25
yhg   0.31  0.03  0.51  0.41 0.58 0.84 1.00  0.39  0.23
sw   -0.27 -0.47 -0.08 -0.21 0.09 0.11 0.39  1.00  0.08
OC    0.07 -0.17  0.34 -0.11 0.12 0.25 0.23  0.08  1.00
>path.analysis(cor.x,cor.y)
Direct(Diagonal) and indirect effect path coefficients
======================================================
df          dm         phcm        sdcm       hdcm         sh
df    0.55808463 -0.27514403  0.77949665 -0.43116034 0.06120801 0.12926736
dm    0.39624009 -0.38752680  0.41267470 -0.27621209 0.01311600 0.08494712
phcm  0.37949755 -0.13950965  1.14631861 -0.49852914 0.21860004 0.19944107
sdcm  0.35717416 -0.15888599  0.84827577 -0.67368803 0.27980805 0.14404077
hdcm  0.07813185 -0.01162580  0.57315931 -0.43116034 0.43720009 0.16989425
```

```
sh    0.19532962 -0.08913116  0.61901205 -0.26273833 0.20111204 0.36933532
yhg   0.17300624 -0.01162580  0.58462249 -0.27621209 0.25357605 0.31024167
sw   -0.15068285  0.18213760 -0.09170549  0.14147449 0.03934801 0.04062689
OC    0.03906592  0.06587956  0.38974833  0.07410568 0.05246401 0.09233383
yhg          sw          OC
df   -0.19718448 -0.03963481 -0.03493300
dm   -0.01908237 -0.06899393  0.08483728
phcm -0.32440028 -0.01174365 -0.16967456
sdcm -0.26079238 -0.03082707  0.05489471
hdcm -0.36892581  0.01321160 -0.05988514
sh   -0.53430635  0.01614752 -0.12476070
yhg  -0.63607898  0.05725028 -0.11477985
sw   -0.24807080  0.14679559 -0.03992342
OC   -0.14629817  0.01174365 -0.49904281

Residual Effect^2 =  0.1806039
> Residualeffect=sqrt(0.1806039)
> Residualeffect
[1] 0.4249752
>
```

```
>library(ggplot2)
>library(ggfortify)
Error in library(ggfortify) : there is no package called ‘ggfortify’
>library(devtools)
Error in library(devtools) : there is no package called ‘devtools’
>library(plyr)
>  library(scales)
>library(grid)
> d<-read.table('clipboard',header=T)
>d
df  dm  phcm sdcm hdcm  sh  yhg sw    OC    PY
1  72 104  82.2 1.34  9.2 186  5.4 50 39.47 235.4
2  67 101  83.4 1.08 10.0 114 10.8 80 40.10 209.8
3  72 110  72.8 0.96  7.4  75  3.5 60 39.00 153.5
4  74 105  87.8 1.76  9.8 100  5.2 55 37.78 235.2
5  70  99  73.6 1.06  7.2  20  2.6 60 39.73  92.6
6  74 107 116.8 1.40 11.4 303 14.6 50 39.38 379.6
7  88 109 119.6 1.70 11.0 162 14.8 55 39.40 294.8
8  77 109 103.8 2.02 16.6 194 16.4 75 38.85 211.4
9  75 109  82.2 1.50  7.4 104  3.6 50 38.88 118.6
10 78 100  99.6 1.68 10.4 108  8.2 65 38.88 333.2
11 75 103 108.8 1.68 10.2 137 10.6 65 38.20 495.6
12 81 110 101.0 1.84 14.8 164 10.4 50 38.68 360.4
13 70 102 107.8 1.68 14.4 284 18.8 80 38.73 213.8
14 65  95  74.8 1.28 14.0 153 11.2 75 38.73 291.2
15 64  92  90.4 1.42 13.0 147  8.8 65 40.33 153.8
16 66  99 101.6 1.50 13.6  19  1.2 60 38.58 351.2
17 70 101  81.2 1.36 12.4 198 12.6 50 39.73 147.0
18 65 101  77.0 1.60 13.4  58  4.4 25 38.78 109.4
19 68 107  94.6 1.56  9.6 112  7.2 50 38.50 172.2
20 72 125  46.0 1.23  8.7  95  4.3 47 37.20  49.0
21 93 137 160.4 2.22 15.0 232 11.0 35 39.99 525.2
>attach(d)
>names(d)
 [1] "df"   "dm"   "phcm" "sdcm" "hdcm" "sh"   "yhg"  "sw"   "OC"   "PY"
>str(d)
'data.frame':   21 obs. of  10 variables:
 $ df  : int  72 67 72 74 70 74 88 77 75 78 ...
 $ dm  : int  104 101 110 105 99 107 109 109 109 100 ...
 $ phcm: num  82.2 83.4 72.8 87.8 73.6 ...
 $ sdcm: num  1.34 1.08 0.96 1.76 1.06 1.4 1.7 2.02 1.5 1.68 ...
 $ hdcm: num  9.2 10 7.4 9.8 7.2 11.4 11 16.6 7.4 10.4 ...
 $ sh  : int  186 114 75 100 20 303 162 194 104 108 ...
 $ yhg : num  5.4 10.8 3.5 5.2 2.6 14.6 14.8 16.4 3.6 8.2 ...
 $ sw  : int  50 80 60 55 60 50 55 75 50 65 ...
 $ OC  : num  39.5 40.1 39 37.8 39.7 ...
 $ PY  : num  235.4 209.8 153.5 235.2 92.6 ...
> d <- na.omit(d)
>id<- scale(d[, 2:10])
> d <- dist(d, method = "euclidean")
> fit <- hclust(d, method="ward.D")
>plot(fit)
>groups<- cutree(fit, k=7)
>rect.hclust(fit, k=5, border="blue")
>
```


Cluster Dendrogram
Height
1200
1000
800
600
400
200
0
16
7
14
10
12
6
11
21
13
17
1
8
20
5
18
2
4
15
19
3
9
d
hclust (*, "ward.D")