UNIVERSITI PUTRA MALAYSIA

GROWTH AND PHYSIOLOGICAL RESPONSES OF BANANA (*Musa* spp.) UNDER DIFFERENT LEVELS OF SALINITY AND ORGANIC FERTILIZER IN THE NORTHERN SULTANATE OF OMAN

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DEDICATION

To the spirit of my late father, whose wishes and aims was the attainment of science even if it costs him to send me to China. To my precious mother who sacrifices for us, to my wives, children and brothers who stood behind me and were supporting me all the time. To my homeland, the Sultanate of Oman, blessed with the sanctifications that God gives us. To every single Omani who sings the song of love for the homeland and works to raise his banner in high blasphemy by faith in God, science and works.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

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Chairman : Associate Professor Yahya bin Awang, PhD
Faculty : Agriculture

Salinity is a major hazard facing banana production in arid regions in the Sultanate of Oman, reducing production up to 50 % when exceeded threshold level of >1.0 dS m^{-1}. Three split-plot experiments were conducted in Malaysia and Sultanate of Oman – one was conducted to evaluate the degree of tolerance to four salinity levels (0.17 (control), 3.0, 6.0 and 9.0 dS m^{-1}) on growth, physiological and biochemical parameters of Diwan, FHIA18, Malindi and Williams cultivars under Malaysia's environment. Two other experiments, conducted in the Sultanate of Oman, examined three salinity levels (0.45, 3.0 and 6.0 dS m^{-1}) on same parameters on Malindi and Somali cultivars. The third experiment assessed responses of the same cultivars supplemented with 7.0 and 14.0 kg chicken manure as soil amendments. Results showed that salinity levels yielded in significant reduction in number of leaves, pseudostem height, girth and average leaf area. Measured parameters decreased in the range of 20.8% to 14.6%, 8.2% to 4.9%, 36.08% to 12.1% and 53.7% to 53.7% respectively. Higher salinity levels caused reductions in photosynthetic and chlorophyll pigments, and secondary metabolic compounds. The reduction was significant when soil was ameliorated with 14.0 kg chicken manure compared to 7.0 kg treatment. Reduction in chlorophyll pigments suggests decrease of photosynthesis components at 6.0 and 9.0 dS m^{-1} salinity levels. The average reduction in C*hl-a*, C*hl-b*, total C*hl*, photosynthesis rate (*PN*), stomata conductance (gs) and transpiration rate (E) were 59.7 %, 43.3 %, 38.3 %, 22.6 %, 62.3 %, 55.8 % respectively. The addition of 7.0 kg of chicken manure gave more positive effects than 14.0 kg treatment on morphological and physiological parameters. All cultivars were observed to be sensitive to salinity, but Malindi and FHIA18 were more tolerant in terms of *Chl-a* (13.4, 10.2 mg cm^{-2} FW), *Chl-b* (7.5 and 5.6 mg cm^{-2} FW), and total chlorophyll than Diwan and Willimas. Total proline content (PRLN) decreased by 11% compared to 34.3 % and by 25.8 % for treatments with the addition of chicken manure. Salinity increased total phenolic (TPC), total flavonoid (TFC) and ferric reducing antioxidant

power assay (FRAP) except FRAP under arid environment. Reduction was significant in K^+/Na^+ and Ca+/Na+ ratios with increasing levels of salinity from a total of 33.3 % and 77.9 % in banana leaves, 94.7 and 57.5 % in banana pseudostem, 94.9 and 87.1 % in roots, respectively. The study observed that higher salinity increased $K^{+/}Na^+$ ratios. Malindi accumulated higher ratio compared to Somali. Ca^+/Na^+ ratio increased leaf and pseudostem by 28.9 % and 165.9% respectively at 9.0 dS m-1 salinity, but decreased by 14.7 % in leaf at 6 dS m^{-1} and by 10.7 % and 40.6% in rhizome and roots at 9.0 dS m^{-1}. Based on morphological, physiological and chemicals parameters, Malindi and FHIA18 showed similar performances in terms of vegetative growth and tolerance at higher salinity levels. Further investigation on responses at molecular levels and yield features would be relevant in future research for banana cultivation in regions of arid environment.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

GERAKBALAS PERTUMBUHAN DAN FISIOLOGI PISANG (*Musa* spp.) TERHADAP TAHAP KEMASINAN YANG BERBEZA DAN BAGA ORGANIK DI UTARA KESULTANAN OMAN

Oleh

KHALID BIN MUBARAK BIN SALEH AL HARTHY

Mei 2019

Pengerusi : Profesor Madya Yahya Bin Awang, PhD
Fakulti : Pertanian

Kenasinan adalah salah satu fenomena semula jadi yang membataskan pertanian di dunia. Ia dikenalpasti sebagai bahaya alam sekitar yang drastik yang dihadapi pertanian di Kesultanan Oman, di kawasan gersang, di mana hujan rendah ≤150 mm setiap tahun, suhu ≥ 42 ºC. Kilang pisang adalah domestik kepada lebih dari 120 buah negara di tanah tropika dan subtropika. Salinitas mengurangkan pengeluaran pisang hingga 50 % apabila ia melebihi tahap ambang> 1.0 dS m^{-1}. Dalam Kesultanan Oman, saliniti banyak mempengaruhi tanaman buah-buahan ekonomi termasuk pisang serta sayur-sayuran dan tanaman lain. Tiga eksperimen reka bentuk split plot telah dijalankan pada 2014-2017 di Malaysia dan Kesultanan Oman untuk mengetahui cara penyelesaian saintifik mungkin untuk menangani masalah kemasinan di Kesultanan Oman untuk pertumbuhan dan hasil pisang. Percubaan pertama dilakukan pada tahun 2014-2015, di bawah penampungan hujan terbuka untuk menilai toleransi garam derajat kultivar pisang Oman di bawah persekitaran Malaysia. Kesan empat tahap kemasinan air pengairan 0.17 kawalan, 3.0, 6.0 dan 9.0 dS m^{-1}, pada pertumbuhan, fisiologi dan ciri biokimia dari empat kultivar pisang (Diwan, FHIA-18, Malindi dan Williams) telah diperiksa.

Yang lain-lain dua kajian sedang dijalankan pada 2016-2017 di Kesultanan Oman. Kesan paras salinasi yang berlainan (0.45, 3.0 dan 6.0 dS m^{-1}) terhadap pertumbuhan, fisiologi dan bahan kimia dari Malindi dan kultivar pisang Somalia telah dikaji dalam percubaan kedua. Walaupun percubaan ketiga dilakukan untuk menilai tindak balas kultivar yang sama hingga 7.0 kg dan 14.0 kg perubahan tanah dengan kompos ayam. Salinitas mempunyai kesan pengurangan ketara ke atas jumlah daun yang dihasilkan, ketinggian pseudostem, larian dan purata daun dengan jumlah pengurangan sebanyak 20.8 % kepada 14.6 %, 4.9 % kepada 8.2 %, 12.1% kepada 36.08 % dan 43.9% kepada 53.7 % masing-masing pada 9.0 dan 6.0 dan 3.0 dS m^{-1} paras salin berbanding dengan

kawalan. Di samping itu paras saliniti yang tinggi menyebabkan perubahan pigmen fotosintesis dan klorofil serta sebatian antioksidan. Pengurangan kadar fotosintesis (PN) adalah antara 23.4 % di tropika hingga 21.8 % dalam persekitaran gersang pada 9.0 dan 6.0 dS m^{-1} masing-masing. Keadaan declininig yang sama diperhatikan dalam konduktans stomata (gs) dikurangkan daripada 59.3 % kepada 65.2 %, pengurangan kadar transpirasi (E) adalah 22.1% kepada 89.4%, Tetapi pengurangan adalah jelas apabila tanah diperbesarkan oleh 14.0 kg kompos ayam daripada 7.0 kg penambahan kompos. Pengurangan dalam *Chl-a, Chl-b dan Chl (a + b)* di bawah 6 dan 9.0 dS m^{-1} masing-masing adalah 59.7 %, 43.3 % dan 38.3 %. Walau bagaimanapun, 7.0 kg daripada penambahan kompos adalah lebih berkesan daripada penambahan kompos ayam 14.0 kg pada kedua-dua ciri morfologi dan fisiologi.

Di bawah persekitaran tropika, jumlah kandungan proline (PRLN) dikurangkan sebanyak 11% berbanding 34.3% dan 25.8% dengan tambahan kompos ayam di persekitaran yang gersang. Sebaliknya ia menunjukkan peningkatan senyawa metabolisme sekunder termasuk jumlah fenolik (TPC) dan jumlah flavaniod (TFC) dan FRAP pada 3.0, 6.0 dan 9.0 dS m^{-1}. Aktiviti FRAP menurun sebanyak 62.02% dan 54.9 % pada 6.0 dan 3.0 dS m^{-1} di bawah persekitaran yang gersang. Natrium klorida menyebabkan pengurangan ketara nisbah K^+/Na^+ dan Ca^+/Na^+ dengan peningkatan tahap kemasinan dari 0.17 hingga 3.0, 6.0 dan 9.0 dS m^{-1} kepada 33.3 % dan 77.9 % dalam daun pisang, 94.7 dan 57.5 % dalam pisang pseudostem, 94.9 dan 87.1 % pengurangan akar. Sebaliknya diperhatikan dalam iklim kering, salin tinggi 3.0 dan 6.0 dS m^{-1} diperhatikan untuk meningkatkan nisbah K^+/Na^+tetapi pada tahap yang rendah berhubung dengan persekitaran tropika. Malindi mengumpul nisbah yang tinggi berbanding dengan pengumpulan rendah oleh cv. "Somali ". Dalam kes nisbah Ca^+/Na^+ meningkat pada daun dan pseudostem sebanyak 28.9 % dan 165.9 % masing-masing pada 9.0 dS m^{-1}, tetapi ia menurun sebanyak 14.7% pada daun pada 6 dS m^{-1} dan 10.7 % dan 40.6% dalam rimpang dan akar pada 9.0 dS m^{-1}.

Berdasarkan keanekaragaman biodiversiti yang tersendiri dan pembezaan kultivar dalam toleransi dan penyesuaian kepada tekanan salinitas dalam persekitaran panas dan tropika yang gersang, kita menyimpulkan bahawa di bawah persekitaran tropika dan tropika, kultivar Malindi dan FHIA-18 telah menyertai pertumbuhan vegetatif dan toleransi yang sama dengan tahap kemasinan yang tinggi . Toleransi itu didasarkan pada ciri morfologi, fisiologi dan kimia mereka. Walaupun paparan di atas, keperluan yang tinggi dalam penyiasatan mendalam terhadap molekul mereka, dan ciri-ciri hasil mereka menjadi lebih penting dalam iklim kering untuk strategi masa depan.

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Declaration by graduate student

I hereby confirm that:

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Signature: _____
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Name of Member of Supervisory Committee: Associate Professor Dr. Rashid bin Abdullah Al Yahyai

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LIST OF ABBREVIATIONS

AAS	Atomic Absorption Spectrophotometer
ANOVA	Analysis of variance
Chl-a	Chlorophyll a
Chl-b	Chlorophyll b
Chl (a+b)	Chlorophyll (a+b)
Chl a/b ratio	Chlorophyll a/b ratio
CCI	Chlorophyll content index
Coff. V	Coefficient of variation
cv.	Cultivar
CEC	Cation Exchange Capacity
cm^2	centimeter square
CP	Crude protein
CPD	Critical Point Dryer
DAT	Day after transplanting
dS m^{-1}	Decisiemens per meter
DW	Dry weight
df	Degree of freedom
DPPH	1,1-Diphenyl-2-picryl-hydrazyl
E	Transpiration
ECw	Electrical conductivity of a water
ECe	Electrical conductivity of soil paste extract
FAO	Food and Agriculture Organization
FRAP	Ferric reducing antioxidant potential
g	Gram

gs	Stomata conductance
ha	Hectare
kPa	kilopascal
LAI	Leaf area index
ALA	Average leaf area
LSD 0.05	Least significant difference at 5% level
m3	Meter cube
MAF	Ministry of Agriculture and Fisheries
mm	millimeter
mM	milimolar
mS/m	Milicisiemens per meter
mmhose/cm	Milimhos per centimeter
Mt	Metric ton
nm	Nanometer
ns	Non-significant
pH	Scale of acidity
P_N	Photosynthesis
ppm	Parts per million
PRLN	proline
Sec	Second
SRF	Salinity research farm
SD	Standard deviation
SE	Standard error
RH	Relative humidity
t	Tonne
TFC	Total flavonoid content

TPC	Total phenolic content
TLDW	Total leaf dry weight
TPSDW	Total pseudostem dry weight
TRHZDW	Total rhizome dry weight
TRDW	Total root dry weight
VPD	Vapor pressure deficit
WUE	Water use efficiency
RWC	Relative water content
ROS	Reactive Oxygen Species
SAS	Statistical Analyses System
SPAD	A portable field unit for chlorophyll content determination
*	Significant at 0.05 probability level
**	Significant at 0.01 probability level
***	Significant at 0.001 probability level
%	Percentage

Chemical Symbols

Cl^-	Chloride
Ca^{2+}	Calcium
Ca^+/Na^+	Calcium sodium ratio
CO_2	Carbon dioxide
K	Potassium
K^+/Na^+	Potassium sodium ratio
Fe	Iron
Mg	Magnesium
Mn	manganese
N^+	Nitrogen
Na+	Sodium
p	Phosphorous
Cu	Copper

CHAPTER 1

INTRODUCTION

Banana (*Musa spp)* is a monocotyledonous, day neutral plant in the genus *Musa,* which encompasses five main sections, namely *Australimusa, Callimusa, Eumusa*, *Incertae sedis and Rhodochlamys. Emusa* represents the most important cultivar of bananas and plantains and constitutes the genome *Musa acuminate* (AA) and *Musa balbisiana* (BB) (Chaurasia et al., 2017; Lassoudière, 2007; Uma, Sathiamoorthy, & Durai, 2005).

The genus *Musa* belongs to the family *Musaceae* and is a member of the order *Zingiberales*. The family includes approximately 1000 species, whereas the section *Eumusa* contains only 11 species. It represents the majority of cultivated edible bananas and the most geographically distributed (Heslop-Harrison & Schwarzacher, 2007; Wang, Vinocur, & Altman, 2003). Globally, banana has become a vital source of food security for approximately 410 million people. It represents the 4th main stable food crop after rice, wheat and corn and ranks 1st in the list of fruits trees in terms of production and areas in about 150 countries including developed and industrialized countries in tropical and subtropical regions of the world (FAO, 2014).

Approximately 126 million tons of bananas were produced from an area of > 5 million hectares during 2016. The international export of banana stood at 17.9 million tons, which is around 12.3 % of the world production (FAO, 2017). In 2014, banana production in the Arab countries reached about 2919.68 (1000 MT) (AOAD, 2017). In 2016, approximately 15.58 (1000MT) were produced from the Sultanate of Oman from an area of about 1421 ha (FAO, 2018). Currently, 50 % of the world production depends on the Cavendish single triploid genotype (D'Hont et al. 2012) and is produced from countries like India, China, the Philippines, Brazil and Ecuador. About 13% of banana production is traded internationally and the balance is produced and used for domestic consumption (Ravi, Uma, Vaganan, & Mustaffa, 2013).

Bananas are susceptible to a wide spectrum of biotic infestations as well as abiotic stresses, affecting growth and development of the crop. The effects of environmental and non-environmental stresses on banana depend on a number of factors including genotype, types of infestations, photoperiod, high light intensity, darkness and ultra-violet, weather (extreme temperature, low or high humidity), irrigation (water - treated or brackish water, flooding, water deficit), nutrient (deficiency, ion toxicity) and physical (wind, typhoons) and numerous other environmental adversities (Nelson, Ploetz, & Kepler, 2006; Ravi & Vaganan, 2016). Abiotic factors play important roles in sustaining plant growth and yield improvement for most economical crops including bananas. Effective plant metabolisms require optimum light intensity, sufficient soil moisture, favorable day and night temperatures and acceptable relative humidity.

Primary salinity occurs naturally and it is widespread in most places in the world, whereas, secondary salinization occurs as a result of human activities such as global warming, insufficient ground water, low rainfall, clearing or irrigation, and sea water intrusion due to over-pumping of fresh ground water. Salinity is mainly associated with agriculture and causes dramatic effects on flora including glycophytes or halophytes and on different soil components such as agriculture land fertility, physical and chemical properties (Munns, 2005; Munns, Goyal, & Passioura, 2005). Food and Agriculture Organization (FAO) estimated salinity (slaine or sodic) covers total areas of over 400 million hectares, which represent > 6% of the world's land area. Out of this, 230 million ha are irrigated agriculture land. However around 19.5% (equivalent to 45 million ha) are associated with salt-affected soil and 32 million ha (2.1%) from 1,500 millions ha are salt-affected under dryland agriculture (FAO, 2018).

Several scientific studies have revealed that abiotic stresses such as salinity of water and soil, have the potential to affect aerial and underground parts and internal constituents of plants through disturbed plant growth and reduced productivity of up to 65-87% (Ravi et al., 2013). The effect of water-soil stress on growth and development of banana has led to fluctuations and instability of banana trading around the world (Heslop-Harrison & Schwarzacher, 2007; Teycheney, Acina, Lockhart, & Candresse, 2007). Bananas are glycophytic plants and very sensitive to salinity measure of >1.0 dS m^{-1}. Good banana growth requires soil with an EC of less than 1.0 dS m^{-1} and pH between 5 and 7 (FAO, 2013). Plants, bananas no less, vary greatly in their tolerance to irrigation with saline water, which inhibits growth by reducing water mobilization thus resulting in reduced growth and development of organs due to osmotic or water-deficits. Salinity has been documented to cause plant cell injuries through entering and disrupting ions for physiological processes (Munns, 2005). Very frequently, plant tolerance to salinity are affected and influenced by several environmental factors including climate, amount of rainfall, soil physical and chemical properties to root growth and plant genotypes and stage of plant growth.

Banana plantation in the Sultanate of Oman occupies an area of approximately 1421 ha, with total annual yield of 18397 tonnes. Banana is mainly cultivated in Dhofar and Al Batinah Governorates in south and north of Oman respectively (FAO, 2019). The most important banana cultivars grown in the Sultanate of Oman includes local genotypes such as Malindi, Somali, Barshi, Fard and Nagal, and some newly introduced genotypes likes Williams and Grand Nine and FHIA. More than 26 % of the cultivated agriculture land (36,764.7 ha) in the Al Batinah governorates are located under salinity constrains as estimated by (MAF, 2012). Currently banana plantations occupy an area of 875.45 ha., with an avreage yield of approximatly 12.0 tonnes/ha (FAO, 2019). There has been an increase in salinity problem in the area, coupled with high alkaline stresses and yield reduction, affecting large proportion of banana acreage in the north of the Sultanate of Oman. The current encounter of abiotic stress was mainly due to high water evaporation rate, low rainfall < 150mm / year and high temperatures of > 45°C for most of the year with high relative humidity (M. Ahmed, Hussain, & Al-Rawahy, 2013; Silva et al., 2009). The situation calls for careful studies to assess plants stress responses under effects of natural and secondary salinity in the arable and cultivated land (MAF, 2012). Salinity had significantly reduced crop

production in the Sultanate of Oman to unpredicted percentages. Banana production was reported to have reduced by 50 % due to salinity and associated problems. It was reported that banana was the least tolerant to salinity compared to other fruit crops (MAF, 2012).

Using materials such as organic manure, animal manure and other sources of organic matter together with selection of tolerant genotypes could alleviate salinity stress on banana (E. Gomes, Willadino, Martins, & Camara, 2001). Organic manure such as from poultry has been reported to be able to decrease and minimize the adverse impact of unhealthy plants affected by biotic or abiotic agents and increases productivity (Tejada, Garcia, Gonzalez, & Hernandez, 2006; Yamano, 2008). Organic manure has been considered favorable in alleviating the impact of salinity by minimizing ionic stresses, rehabilitating plant metabolic activities when added in recommended amount prior to planting. The mechanism of slow-release nutrients elements by adding manure becomes readily absorbed by plants due to increase in soil water retention, decrease of fertilizer leaching and run-off resulting in manure-treated soil provides good growth environment for root system (Stokes, Cody, & Maheswaran, 2003). In arid and semi-arid areas with basic pH, the use of organic manures plays a vital role in replacing exchangeable sodium ion when soil irrigated with water rich in divalent cations (Garcia, Hernandez, Pascual, Moreno, & Ros, 2000). Organic manure increases soil organic matter and improves their poor physio-chemicals and biological charcteristics, increases nurients efficiency for good plant growth and high yield (Li, Li, Cui, & Rengel, 2006; Qadir, Qureshi, & Ahmad, 2002). It also lowers exchangable sodium percentage, decreases electric conductivity and accelerates Na^+ leaching, water infiltration, aggregates stabiltiy and raises water holding capacity (Tejeda et al., 2006). Salinity problems in the Sultanate of Oman has caused major limiting phenomenon in agriculture production in fruits tress, vegetables, field crop and fodders as reported by (MAF, 2012). High salinity in soil and irrigation water registered >5.0 dS m^{-1}, while in some area it was above 15.0 dS m^{-1}. Salinity has caused annual losses in agricultural production of about US$ 19 to 36 million. Therefore, understanding of banana responses to different degree of water quality is crucial for proper growth to obtain high productivity. Organic amendments have been reported to improve soil structure through improving C/N ratio during decompostition processes of organic matter by microorgansms. This increases soil aeration, permeability and helps to leach salt below the root zone through improving drainage conditions (Tejada et al., 2006). Studies on the capabilities of banana to cope with high salinity appear as good strategy and initiative for sustainable banana growth and production.

The present study was conducted to test the performance of selected banana cultivars under saline irrigation water. The study has the following objectives:

1. To identify potential tolerant banana cultivars based on vegetative growth under different saline irigation water irrigation under local environment (State of Selangor, Malaysia);
2. To examine salinity stresses on physiology, morphology and biochemical charcteristics of selected banana cultivars;
3. To evaluate the effect of differernt rates of poultry manure supplementation as soil amendments on growth, flowering, biochemicals charateristics and nutrients composition of Omani local banana cultivars irrigated with saline water under environment of northern Al Batinah Governorate in the Sultanate of Oman.

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Khalid bin Mubarak bin Saleh AL Harthy was born on 1st January, 1967 in Northern Al Batinah Governorate, Wilayat (province) Al Suwaiq, Sur Haiyan., Sultanate of Oman. He obtained his Secondary School Certificate from Sohar Secondary School, Al Batinah North Governorate, wilayat (province) Sohar. He graduated in October 1990, with B.Sc. in Science, majoring in plant science from Faculty of Agriculture and Marine Sciences, Sultan Qaboos University (SQU) in Muscat. He earned his M.Sc. in sciences, majoring horticulture in October 2009 from SQU. His master's thesis was supervised by Assoc. Prof. Dr. Rashid Al Yahyai. He got married in 1995 and has been blessed with nine children two of whom are currently in Technical College. He worked as an Agriculture engineer from 21/10/1990 to 30/4/1992, was head department of agriculture extension center in southern Al Batinah Governorate in Wilayat (province) Al Musanaah from 1/5/1991 to 19/5/1998, Director of Agriculture Development Center in Al Batinah North Governorate, Wilayat (province) Al Suwaiq from 20/5/1998 to 19/3/2000. Specialist of agriculture extension and plant production in Al Batinah North and South Governorates and Director General of Agriculture and Animal Wealth from mid20/2/2000 to 12/10/2001 and Specialist of plant production from 13/10/2001 to 14/6/2006. Director of Agriculture Development Center in Northern Al Batinah Governorate, Wilayat (province) Liwa from 15/8/2006 to 28/3/2008. Director of Animal Wealth in Al Batinah North and South Governorates, Directorate General of Agriculture and Animals Wealth at Al Batinah North and South Governorates from 29/3/2008 to date.

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LIST OF PUBLICATIONS

Al Harthy K, M., Aishah, S. H., Yahya, A., Roslan, I. & AL Yahyai, R. 2018. Effects of saline irrigation water on morphological characteristics of banana (Musa spp.). *International Food Research Journal,* 25, S195-S200.

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