*UNIVERSITE DE YAOUNDE I*

*FACULTE DES SCIENCES*

*CENTRE DE RECHERCHE ET DE FORMATION DOCTORALE SCIENCE DE LA VIE SANTE ET ENVIRONNEMENT*

*UNITE DE RECHERCHE ET DE FORMATION DOCTORALE EN SCIENCES DE LA VIE*

UNIVERSITY OF YAOUNDE I

FACULTY OF SCIENCES

POSTE GRADUATE AND TRAINING SCHOOL FOR LIFE SCIENCES HEALTH AND THE ENVIRONMENT

POST GRADUATE AND TRAINING UNIT OF LIFE SCIENCES-HEALTH

DEPARTMENT OF BIOCHIMISTRY
*DEPARTEMENT DE BIOCHIMIE*

LABORATORY OF PHYTOBIOCHEMISTRY AND MEDICAL PLANT STUDIES
*LABORATOIRE DE PHYTOBIOCHIMIE ET D'ETUDES DES PLANTES MEDICINALES*

# EVALUATION OF THE COMBINED USE OF CLOVE BASIL EXTRACT AND CASSAVA PEELS COMPOST ON THE YIELD, NUTRIENT CONTENT, ORGANOLEPTIC AND ANTIOXIDANT PROPERTIES OF SWEET PEPPER (*Capsicuum Annuum*.L)

**PhD Thesis**

*Submitted in partial fulfilment of the requirements for the degree of Doctor/PhD in Biochemistry*

*Specialty*
Biotechnology and Development

***By***
**ONGUENE Dieudonné**
**14Z4692**
**MSc Biochemistry**



*Members of the jury:*

| | | |
|---|---|---|
| **President:** | **FOKOU Elie, Pr;** | Université de Yaoundé I |
| **Rapporteur :** | **NGUEFACK Julienne, MC ;** | Université de Yaoundé I |
| **Members :** | **NGAKOU Albert, Pr ;** | Université de Ngaoundéré |
| | **KANSCI Germain, Pr ;** | Université de Yaoundé I |
| | **EFFA ONOMO Pierre, MC ;** | Université de Yaoundé I |

Academic year 2021-2022

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# EVALUATION OF THE COMBINED USE OF CLOVE BASIL EXTRACT AND CASSAVA PEELS COMPOST ON THE YIELD, NUTRIENT CONTENT, ORGANOLEPTIC AND ANTIOXIDANT PROPERTIES OF SWEET PEPPER (*Capsicuum Annuum*.L)

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| **President:** | **FOKOU Elie, Pr;** | Université de Yaoundé I |
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| | **KANSCI Germain, Pr ;** | Université de Yaoundé I |
| | **EFFA ONOMO Pierre, MC ;** | Université de Yaoundé I |

Academic year 2021-2022

REPUBLIQUE DU CAMEROUN
Paix-Travail-Patrie
************
UNIVERSITE DE YAOUNDE I
***********
FACULTE DES SCIENCES
B.P. 812 Yaoundé
***********
DEPARTEMENT DE BIOCHIMIE

REPUBLIC OF CAMEROON
Peace-Work-Fatherland
****************
UNIVERSITY OF YAOUNDE I
************
FACULTY OF SCIENCE
P.O.Box 812 Yaoundé
************
DEPARTMENT OF BIOCHEMISTRY

# ATTESTATION DE CORRECTION DE THESE DE DOCTORAT/Ph.D

Nous, membres du Jury de thèse de Doctorat / Ph.D de **Monsieur ONGUENE Dieudonné (Matricule 14Z4692)** préparée sous la direction du Professeur NGUEFACK Julienne intitulée " Evaluation of the combined use of clove basil extract and cassava peels compost on the yield, nutrient content, organoleptic and antioxidant properties of sweet pepper (*Capsicuum Annuum*.L)" et soutenue publiquement **le 02 Février 2022** en vue de l'obtention du grade de Docteur / Ph.D en Biochimie, attestons que toutes les corrections demandées par le Jury de soutenance ont été effectuées.

En foi de quoi la présente attestation lui est établie et délivrée pour servir et valoir ce que de droit.

Fait à Yaoundé le...11/05/2022

**EXAMINATEURS**

**LE PRESIDENT DU JURY**

Pr. Elie Fokou
Dr. d'Etat en Biochimie
Nutrition et Sciences Alimentaires

| UNIVERSITÉ DE YAOUNDÉ I<br>**Faculté des Sciences**<br>Division de la Programmation et du Suivi des Activités Académiques | | THE UNIVERSITY OF YAOUNDE I<br>**Faculty of Science**<br>Division of Programming and Follow-up of Academic Affaires |
|---|---|---|
| **LISTE DES ENSEIGNANTS PERMANENTS** | | **LIST OF PERMANENT TEACHING STAFF** |

**ANNÉE ACADEMIQUE 2021/2022**
(Par Département et par Grade)
**DATE D'ACTUALISATION 22 septembre 2021**

## ADMINISTRATION

**DOYEN :** TCHOUANKEU Jean- Claude, *Maître de Conférences*
**VICE-DOYEN / DPSAA :** ATCHADE Alex de Théodore, *Maître de Conférences*
**VICE-DOYEN / DSSE :** NYEGUE Maximilienne Ascension, *Professeur*
**VICE-DOYEN / DRC :** ABOSSOLO Monique, *Maître de Conférences*
**Chef Division Administrative et Financière :** NDOYE FOE Marie C. F., *Maître de Conférences*
**Chef Division des Affaires Académiques, de la Scolarité et de la Recherche DAASR :** AJEAGAH Gideon AGHAINDUM, *Professeur*

## 1- DÉPARTEMENT DE BIOCHIMIE (BC) (38)

| N° | NOMS ET PRÉNOMS | GRADE | OBSERVATIONS |
|---|---|---|---|
| 1 | BIGOGA DAIGA Jude | Professeur | En poste |
| 2 | FEKAM BOYOM Fabrice | Professeur | En poste |
| 3 | FOKOU Elie | Professeur | En poste |
| 4 | KANSCI Germain | Professeur | En poste |
| 5 | MBACHAM FON Wilfried | Professeur | En poste |
| 6 | MOUNDIPA FEWOU Paul | Professeur | Chef de Département |
| 7 | NINTCHOM PENLAP V. épse BENG | Professeur | En poste |
| 8 | OBEN Julius ENYONG | Professeur | En poste |
| 9 | ACHU Merci BIH | Maître de Conférences | En poste |
| 10 | ATOGHO Barbara Mma | Maître de Conférences | En poste |
| 11 | AZANTSA KINGUE GABIN BORIS | Maître de Conférences | En poste |
| 12 | BELINGA née NDOYE FOE M. C. F. | Maître de Conférences | Chef DAF / FS |
| 13 | BOUDJEKO Thaddée | Maître de Conférences | En poste |
| 14 | DJUIDJE NGOUNOUE Marcelline | Maître de Conférences | En poste |
| 15 | EFFA ONOMO Pierre | Maître de Conférences | En poste |

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|---|---|---|---|
| 16 | EWANE Cécile Anne | Maître de Conférences | En poste |
| 17 | MOFOR née TEUGWA Clotilde | Maître de Conférences | Inspecteur de Service MINESUP |
| 18 | NANA Louise épouse WAKAM | Maître de Conférences | En poste |
| 19 | NGONDI Judith Laure | Maître de Conférences | En poste |
| 20 | NGUEFACK Julienne | Maître de Conférences | En poste |
| 21 | NJAYOU Frédéric Nico | Maître de Conférences | En poste |
| 22 | TCHANA KOUATCHOUA Angèle | Maître de Conférences | En poste |
| 23 | AKINDEH MBUH NJI | Chargé de Cours | En poste |
| 24 | BEBEE Fadimatou | Chargée de Cours | En poste |
| 25 | BEBOY EDJENGUELE Sara Nathalie | Chargé de Cours | En poste |
| 26 | DAKOLE DABOY Charles | Chargé de Cours | En poste |
| 27 | DJUIKWO NKONGA Ruth Viviane | Chargée de Cours | En poste |
| 28 | DONGMO LEKAGNE Joseph Blaise | Chargé de Cours | En poste |
| 29 | FONKOUA Martin | Chargé de Cours | En poste |
| 30 | KOTUE KAPTUE Charles | Chargé de Cours | En poste |
| 31 | LUNGA Paul KEILAH | Chargé de Cours | En poste |
| 32 | MANANGA Marlyse Joséphine | Chargée de Cours | En poste |
| 33 | MBONG ANGIE M. Mary Anne | Chargée de Cours | En poste |
| 34 | Palmer MASUMBE NETONGO | Chargé de Cours | En poste |
| 35 | PECHANGOU NSANGOU Sylvain | Chargé de Cours | En poste |
| 36 | MBOUCHE FANMOE Marceline Joëlle | Assistante | En poste |
| 37 | OWONA AYISSI Vincent Brice | Assistant | En poste |
| 38 | WILFRIED ANGIE Abia | Assistante | En poste |

**2- DÉPARTEMENT DE BIOLOGIE ET PHYSIOLOGIE ANIMALES (BPA) (46)**

| | | | |
|---|---|---|---|
| 1 | AJEAGAH Gideon AGHAINDUM | Professeur | *DAARS/FS* |
| 2 | BILONG BILONG Charles-Félix | Professeur | Chef de Département |
| 3 | DIMO Théophile | Professeur | En Poste |
| 4 | DJIETO LORDON Champlain | Professeur | En Poste |
| 5 | DZEUFIET DJOMENI Paul Désiré | Professeur | En Poste |
| 6 | ESSOMBA née NTSAMA MBALA | Professeur | *Vice Doyen/FMSB/UYI* |
| 7 | FOMENA Abraham | Professeur | En Poste |
| 8 | KEKEUNOU Sévilor | Professeur | En poste |
| 9 | NJAMEN Dieudonné | Professeur | En poste |
| 10 | NJIOKOU Flobert | Professeur | En Poste |

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|---|---|---|---|
| 11 | NOLA Moïse | Professeur | En poste |
| 12 | TAN Paul VERNYUY | Professeur | En poste |
| 13 | TCHUEM TCHUENTE Louis Albert | Professeur | *Inspecteur de service*<br>*Coord.Progr./MINSANTE* |
| 14 | ZEBAZE TOGOUET Serge Hubert | Professeur | *En poste* |

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|---|---|---|---|
| 15 | BILANDA Danielle Claude | Maître de Conférences | En poste |
| 16 | DJIOGUE Séfirin | Maître de Conférences | En poste |
| 17 | JATSA BOUKENG Hermine épse MEGAPTCHE | Maître de Conférences | En Poste |
| 18 | LEKEUFACK FOLEFACK Guy B. | Maître de Conférences | En poste |
| 19 | MEGNEKOU Rosette | Maître de Conférences | En poste |
| 20 | MONY Ruth épse NTONE | Maître de Conférences | En Poste |
| 21 | NGUEGUIM TSOFACK Florence | Maître de Conférences | En poste |
| 22 | TOMBI Jeannette | Maître de Conférences | En poste |
| 23 | ALENE Désirée Chantal | Chargée de Cours | En poste |
| 24 | ATSAMO Albert Donatien | Chargé de Cours | En poste |
| 25 | BELLET EDIMO Oscar Roger | Chargé de Cours | En poste |
| 26 | DONFACK Mireille | Chargée de Cours | En poste |
| 27 | ETEME ENAMA Serge | Chargé de Cours | En poste |
| 28 | GOUNOUE KAMKUMO Raceline | Chargée de Cours | En poste |
| 29 | KANDEDA KAVAYE Antoine | Chargé de Cours | En poste |
| 30 | MAHOB Raymond Joseph | Chargé de Cours | En poste |
| 31 | MBENOUN MASSE Paul Serge | Chargé de Cours | En poste |
| 32 | MOUNGANG Luciane Marlyse | Chargée de Cours | En poste |
| 33 | MVEYO NDANKEU Yves Patrick | Chargé de Cours | En poste |
| 34 | NGOUATEU KENFACK Omer Bébé | Chargé de Cours | En poste |
| 35 | NGUEMBOK | Chargé de Cours | En poste |
| 36 | NJUA Clarisse Yafi | Chargée de Cours | Chef Div. UBA |
| 37 | NOAH EWOTI Olive Vivien | Chargée de Cours | En poste |
| 38 | TADU Zephyrin | Chargé de Cours | En poste |
| 39 | TAMSA ARFAO Antoine | Chargé de Cours | En poste |
| 40 | YEDE | Chargé de Cours | En poste |

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|---|---|---|---|
| 41 | BASSOCK BAYIHA Etienne Didier | Assistant | En poste |
| 42 | ESSAMA MBIDA Désirée Sandrine | Assistante | En poste |
| 43 | KOGA MANG DOBARA | Assistant | En poste |
| 44 | LEME BANOCK Lucie | Assistante | En poste |
| 45 | YOUNOUSSA LAME | Assistant | En poste |

## 3- DÉPARTEMENT DE BIOLOGIE ET PHYSIOLOGIE VÉGÉTALES (BPV) (33)

| | | | |
|---|---|---|---|
| 1 | AMBANG Zachée | Professeur | Chef Division/UYII |
| 2 | BELL Joseph Martin | Professeur | En poste |
| 3 | DJOCGOUE Pierre François | Professeur | En poste |
| 4 | MBOLO Marie | Professeur | En poste |
| 5 | MOSSEBO Dominique Claude | Professeur | En poste |
| 6 | YOUMBI Emmanuel | Professeur | Chef de Département |
| 7 | ZAPFACK Louis | Professeur | En poste |
| 8 | ANGONI Hyacinthe | Maître de Conférences | En poste |
| 9 | BIYE Elvire Hortense | Maître de Conférences | En poste |
| 10 | KENGNE NOUMSI Ives Magloire | Maître de Conférences | En poste |
| 11 | MALA Armand William | Maître de Conférences | En poste |
| 12 | MBARGA BINDZI Marie Alain | Maître de Conférences | CT/ MINESUP |
| 13 | NDONGO BEKOLO | Maître de Conférences | *CE / MINRESI* |
| 14 | NGODO MELINGUI Jean Baptiste | Maître de Conférences | En poste |
| 15 | NGONKEU MAGAPTCHE Eddy L. | Maître de Conférences | En poste |
| 16 | TONFACK Libert Brice | Maître de Conférences | En poste |
| 17 | TSOATA Esaïe | Maître de Conférences | En poste |
| 18 | DJEUANI Astride Carole | Chargé de Cours | En poste |
| 19 | GOMANDJE Christelle | Chargée de Cours | En poste |
| 20 | MAFFO MAFFO Nicole Liliane | Chargé de Cours | En poste |
| 21 | MAHBOU SOMO TOUKAM. Gabriel | Chargé de Cours | En poste |
| 22 | NGALLE Hermine BILLE | Chargée de Cours | En poste |
| 23 | NNANGA MEBENGA Ruth Laure | Chargé de Cours | En poste |
| 24 | NOUKEU KOUAKAM Armelle | Chargé de Cours | En poste |
| 25 | ONANA JEAN MICHEL | Chargé de Cours | En poste |
| 26 | GODSWILL NTSOMBAH NTSEFONG | Assistant | En poste |
| 27 | KABELONG BANAHO Louis-Paul-Roger | Assistant | En poste |

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|---|---|---|---|
| 28 | KONO Léon Dieudonné | Assistant | En poste |
| 29 | LIBALAH Moses BAKONCK | Assistant | En poste |
| 30 | LIKENG-LI-NGUE Benoit C | Assistant | En poste |
| 31 | TAEDOUNG Evariste Hermann | Assistant | En poste |
| 32 | TEMEGNE NONO Carine | Assistant | En poste |

**4- DÉPARTEMENT DE CHIMIE INORGANIQUE (CI) (33)**

| | | | |
|---|---|---|---|
| 1 | AGWARA ONDOH Moïse | Professeur | *Chef de Département* |
| 2 | DJOUFAC WOUMFO Emmanuel | Professeur | En poste |
| 3 | Florence UFI CHINJE épouse MELO | Professeur | *Recteur Univ.Ngaoundere* |
| 4 | GHOGOMU Paul MINGO | Professeur | *Ministre Chargé deMiss.PR* |
| 5 | NANSEU Njiki Charles Péguy | Professeur | En poste |
| 6 | NDIFON Peter TEKE | Professeur | *CT MINRESI* |
| 7 | NDIKONTAR Maurice KOR | Professeur | *Vice-Doyen Univ. Bamenda* |
| 8 | NENWA Justin | Professeur | En poste |
| 9 | NGAMENI Emmanuel | Professeur | *DOYEN FS UDs* |
| 10 | NGOMO Horace MANGA | Professeur | *Vice Chancelor/UB* |

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|---|---|---|---|
| 11 | ACAYANKA Elie | Maître de Conférences | En poste |
| 12 | BABALE née DJAM DOUDOU | Maître de Conférences | *Chargée Mission P.R.* |
| 13 | EMADACK Alphonse | Maître de Conférences | En poste |
| 14 | KAMGANG YOUBI Georges | Maître de Conférences | En poste |
| 15 | KEMMEGNE MBOUGUEM Jean C. | Maître de Conférences | En poste |
| 16 | KONG SAKEO | Maître de Conférences | En poste |
| 17 | NDI NSAMI Julius | Maître de Conférences | En poste |
| 18 | NJIOMOU C. épse DJANGANG | Maître de Conférences | En poste |
| 19 | NJOYA Dayirou | Maître de Conférences | En poste |
| 20 | TCHAKOUTE KOUAMO Hervé | Maître de Conférences | En poste |

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| 21 | BELIBI BELIBI Placide Désiré | Chargé de Cours | CS/ ENS Bertoua |
| 22 | CHEUMANI YONA Arnaud M. | Chargé de Cours | En poste |
| 23 | KENNE DEDZO GUSTAVE | Chargé de Cours | En poste |
| 24 | KOUOTOU DAOUDA | Chargé de Cours | En poste |

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|---|---|---|---|
| 25 | MAKON Thomas Beauregard | Chargé de Cours | En poste |
| 26 | MBEY Jean Aime | Chargé de Cours | En poste |
| 27 | NCHIMI NONO KATIA | Chargé de Cours | En poste |
| 28 | NEBA nee NDOSIRI Bridget NDOYE | Chargée de Cours | CT/ MINFEM |
| 29 | NYAMEN Linda Dyorisse | Chargée de Cours | En poste |
| 30 | PABOUDAM GBAMBIE A. | Chargée de Cours | En poste |

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|---|---|---|---|
| 31 | NJANKWA NJABONG N. Eric | Assistant | En poste |
| 32 | PATOUOSSA ISSOFA | Assistant | En poste |
| 33 | SIEWE Jean Mermoz | Assistant | En Poste |

| **5- DÉPARTEMENT DE CHIMIE ORGANIQUE (CO) (34)** | | | |
|---|---|---|---|
| 1 | DONGO Etienne | Professeur | Vice-Doyen/FSE/UYI |
| 2 | GHOGOMU TIH Robert Ralph | Professeur | Dir. IBAF/UDA |
| 3 | NGOUELA Silvère Augustin | Professeur | Chef de Département UDS |
| 4 | NYASSE Barthélemy | Professeur | En poste |
| 5 | PEGNYEMB Dieudonné Emmanuel | Professeur | *Directeur/ MINESUP/* Chef de Département |
| 6 | WANDJI Jean | Professeur | En poste |

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| 7 | Alex de Théodore ATCHADE | Maître de Conférences | Vice-Doyen / DPSAA |
| 8 | AMBASSA Pantaléon | Maître de Conférences | En poste |
| 9 | EYONG Kenneth OBEN | Maître de Conférences | En poste |
| 10 | FOLEFOC Gabriel NGOSONG | Maître de Conférences | En poste |
| 11 | FOTSO WABO Ghislain | Maître de Conférences | En poste |
| 12 | KEUMEDJIO Félix | Maître de Conférences | En poste |
| 13 | KEUMOGNE Marguerite | Maître de Conférences | En poste |
| 14 | KOUAM Jacques | Maître de Conférences | En poste |
| 15 | MBAZOA née DJAMA Céline | Maître de Conférences | En poste |
| 16 | MKOUNGA Pierre | Maître de Conférences | En poste |
| 17 | MVOT AKAK CARINE | Maître de Conférences | En poste |
| 18 | NGO MBING Joséphine | Maître de Conférences | Sous/Direct. MINERESI |

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| 19 | NGONO BIKOBO Dominique Serge | Maître de Conférences | C.E/ MINESUP |
| 20 | NOTE LOUGBOT Olivier Placide | Maître de Conférences | C.S/ MINESUP |
| 21 | NOUNGOUE TCHAMO Diderot | Maître de Conférences | En poste |
| 22 | TABOPDA KUATE Turibio | Maître de Conférences | En poste |
| 23 | TAGATSING FOTSING Maurice | Maître de Conférences | En poste |
| 24 | TCHOUANKEU Jean-Claude | Maître de Conférences | *Doyen /FS/ UYI* |
| 25 | TIH née NGO BILONG E. Anastasie | Maître de Conférences | En poste |
| 26 | YANKEP Emmanuel | Maître de Conférences | En poste |
| 27 | ZONDEGOUMBA Ernestine | Maître de Conférences | En poste |

| | | | |
|---|---|---|---|
| 28 | KAMTO Eutrophe Le Doux | Chargé de Cours | En poste |
| 29 | NGNINTEDO Dominique | Chargé de Cours | En poste |
| 30 | NGOMO Orléans | Chargée de Cours | En poste |
| 31 | OUAHOUO WACHE Blandine M. | Chargée de Cours | En poste |
| 32 | SIELINOU TEDJON Valérie | Chargé de Cours | En poste |

| | | | |
|---|---|---|---|
| 33 | MESSI Angélique Nicolas | Assistant | En poste |
| 34 | TSEMEUGNE Joseph | Assistant | En poste |

**6- DÉPARTEMENT D'INFORMATIQUE (IN) (25)**

| | | | |
|---|---|---|---|
| 1 | ATSA ETOUNDI Roger | Professeur | *Chef Div.MINESUP* |
| 2 | FOUDA NDJODO Marcel Laurent | Professeur | *Chef Dpt ENS/Chef IGA.MINESUP* |

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| 3 | NDOUNDAM Réné | Maître de Conférences | En poste |

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| 4 | ABESSOLO ALO'O Gislain | Chargé de Cours | En poste |
| 5 | AMINOU Halidou | Chargé de Cours | *Chef de Département* |
| 6 | DJAM Xaviera YOUH - KIMBI | Chargé de Cours | En Poste |
| 7 | DOMGA KOMGUEM Rodrigue | Chargé de Cours | En poste |
| 8 | EBELE Serge Alain | Chargé de Cours | En poste |
| 9 | KOUOKAM KOUOKAM E. A. | Chargé de Cours | En poste |
| 10 | MELATAGIA YONTA Paulin | Chargé de Cours | En poste |
| 11 | MONTHE DJIADEU Valery M. | Chargé de Cours | En poste |
| 12 | MOTO MPONG Serge Alain | Chargé de Cours | En poste |
| 13 | OLLE OLLE Daniel Claude Delort | Chargé de Cours | Directeur adjoint Enset. Ebolowa |

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|---|---|---|---|
| 14 | TAPAMO Hyppolite | Chargé de Cours | En poste |
| 15 | TINDO Gilbert | Chargé de Cours | En poste |
| 16 | TSOPZE Norbert | Chargé de Cours | En poste |
| 17 | WAKU KOUAMOU Jules | Chargé de Cours | En poste |

| | | | |
|---|---|---|---|
| 18 | BAYEM Jacques Narcisse | Assistant | En poste |
| 19 | EKODECK Stéphane Gaël Raymond | Assistant | En poste |
| 20 | HAMZA Adamou | Assistant | En poste |
| 21 | JIOMEKONG AZANZI Fidel | Assistant | En poste |
| 22 | MAKEMBE. S . Oswald | Assistant | En poste |
| 23 | MESSI NGUELE Thomas | Assistant | En poste |
| 24 | MEYEMDOU Nadège Sylvianne | Assistante | En poste |
| 25 | NKONDOCK. MI. BAHANACK.N. | Assistant | En poste |

**7- DÉPARTEMENT DE MATHÉMATIQUES (MA) (30)**

| | | | |
|---|---|---|---|
| 1 | AYISSI Raoult Domingo | Professeur | Chef de Département |
| 2 | EMVUDU WONO Yves S. | Professeur | *Inspecteur MINESUP* |

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|---|---|---|---|
| 3 | KIANPI Maurice | Maître de Conférences | En poste |
| 4 | MBANG Joseph | Maître de Conférences | En poste |
| 5 | MBEHOU Mohamed | Maître de Conférences | En poste |
| 6 | MBELE BIDIMA Martin Ledoux | Maître de Conférences | En poste |
| 7 | NKUIMI JUGNIA Célestin | Maître de Conférences | En poste |
| 8 | NOUNDJEU Pierre | Maître de Conférences | *Chef service des programmes & Diplômes/FS/UYI* |
| 9 | TCHAPNDA NJABO Sophonie B. | Maître de Conférences | Directeur/AIMS Rwanda |
| 10 | TCHOUNDJA Edgar Landry | Maître de Conférences | En poste |

| | | | |
|---|---|---|---|
| 11 | AGHOUKENG JIOFACK Jean Gérard | Chargé de Cours | Chef Cellule MINPLAMAT |
| 12 | CHENDJOU Gilbert | Chargé de Cours | En poste |
| 13 | DJIADEU NGAHA Michel | Chargé de Cours | En poste |
| 14 | DOUANLA YONTA Herman | Chargé de Cours | En poste |
| 15 | FOMEKONG Christophe | Chargé de Cours | En poste |
| 16 | KIKI Maxime Armand | Chargé de Cours | En poste |
| 17 | MBAKOP Guy Merlin | Chargé de Cours | En poste |
| 18 | MENGUE MENGUE David Joe | Chargé de Cours | En poste |
| 19 | NGUEFACK Bernard | Chargé de Cours | En poste |

| | | | |
|---|---|---|---|
| 20 | NIMPA PEFOUKEU Romain | Chargée de Cours | En poste |
| 21 | POLA DOUNDOU Emmanuel | Chargé de Cours | En poste |
| 22 | TAKAM SOH Patrice | Chargé de Cours | En poste |
| 23 | TCHANGANG Roger Duclos | Chargé de Cours | En poste |
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|---|---|---|---|
| 41 | FEUMBA Roger | Assistant | En poste |
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**Répartition chiffrée des Enseignants de la Faculté des Sciences de l'Université de Yaoundé I**

| NOMBRE D'ENSEIGNANTS | | | | | |
|---|---|---|---|---|---|
| **DÉPARTEMENT** | **Professeurs** | **Maîtres de Conférences** | **Chargés de Cours** | **Assistants** | **Total** |
| BCH | 8 (01) | 14 (10) | 13 (05) | 3 (02) | **38 (18)** |
| BPA | 15 (01) | 8 (06) | 18 (05) | 05 (02) | **46 (14)** |
| BPV | 07 (01) | 10 (01) | 9 (06) | 07 (01) | **33 (9)** |
| CI | 10 (01) | 10 (02) | 10 (02) | 03 (0) | **33 (5)** |
| CO | 6 (0) | 21 (05) | 05 (02) | 02 (0) | **34(7)** |
| IN | 2 (0) | 1 (0) | 14 (01) | 08 (01) | **25 (2)** |
| MAT | 2 (0) | 8 (0) | 15 (01) | 05 (02) | **30 (3)** |
| MIB | 3 (0) | 4 (02) | 05 (01) | 06 (02) | **18 (5)** |
| PHY | 15 (0) | 14 (02) | 09 (03) | 02 (0) | **40 (5)** |
| ST | 7 (1) | 15 (01) | 18 (05) | 02 (0) | **42(7)** |
| **Total** | **75 (5)** | **105 (29)** | **116 (31)** | **43 (10)** | **339 (75)** |

Soit un total de **339 (**75**)** dont :

- Professeurs **75 (5)**
- Maîtres de Conférences **105 (**29**)**
- Chargés de Cours **116 (31)**
- Assistants **43** (10**)**

( ) = Nombre de Femmes **75**

# DEDICATION

*To my dear parents: ONGUENE Nyama and TSIMI BINELE Jeanne, including all my uncles and to my entire family.*

# ACKNOWLEDGMENTS

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## LIST OF ABREVIATIONS

**AMO**: Ammoniac monooxygenase

**AOAC**: Association of official Analytical chemists

**ASA**: Ascorbique acid

**AVRDC**: Asian Vegetable Reseach and Development Centre (The world vegetable Centre)

**CP**: Cassava peels compost

**CVD**: Cadiovascular disease

**CHD**: Coronary heart disease

**DI**: Disease incidence

**DS**: Disease severity

**DPPH**: 2,2–diphenyl–1–picrylhydrazyl

**DMSO**: dimethyl sulfoxide

**DAP**: Diammonium phosphate

**ECME**: Easten Corridor Medical Engineering Centre

**FRAP**: Ferric reducing antioxidant power

**FAO**: Food and agricultural organization

**HAO**: Hydroxylamine oxidoreductase

**IRS**: Induced systemic resistance

**ICM**: Integrated crop management

**IPM**: Integrated pest management

**ISTA**: Internationl Seed Testing Association

**MINADER**: Ministry of Agriculture and Rural Development

**SOM**: Soil organic matter

**SD**: Superoxide dismutase

**SAR**: Systemic acquired resistance

**RDA**: Recommended dietary allowance

**USDA**: United States Department of Agriculture

**USEPA**: United States Environmental Protection Agency

**WHO**: World Health Organization

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## ABSTRACT

This work was carried out to assess the effect of the combined use of clove basil (*Ocimum gratissimum)* aqueous extract and cassava peels compost (CP) on the yield, nutrient content, organoleptic and antioxidant properties of sweet pepper (*Capsicum annuum* L.). As results, according to the survey, the most sweet pepper varieties cultivated by farmers were "Yolo wonder" and "Simba". 89 % of respondents had a sweet pepper field with a surface area between 0.5 and 1 hectare. Cypermethrin and Mancozeb represented respectively 63% and 85% of active ingredients used by the sampled growers to fight against sweet pepper diseases. After three months of composting, composts produced from cassava peels had a texture similar to the soil's texture. Their pH, was slightly acid (6.50-6.73), appropriate for the cultivation of sweet pepper. The composts C/N ratios were between 13.15 to 13.42. The produced composts showed a germination index and the percentage of emergence higher than 80%, indicating the absence of phytotoxicity. Twelve treatments (CP1-B, CP1-E, CP1-S, CP2-B, CP2-E, CP2-S, NPK-B, NPK-E, NPK-S, C-B, C-E and C-S) were applied both in pot and field experiments. The experiments were a split plot design. CP1-B and CP2-B positively and significantly increased the shelf life of fruits from 70 days to 90 days under $4^0$C and from 23 days to 26 days under room temperature, the organoleptic properties, fruit nutritional qualities and antioxidant properties compared to the conventional treated fruits. They exhibited the highest values of nutritional qualities and antioxidant properties. Organic fruits had the best values of Na/K and Ca/P ratios which are good indicators of their nutritional values. Treatment CP2-B increased the yield by 93% in pot experiment and 187% under field experiments as compared respectively, to NPK-B with 6 kg/m$^2$ and 4 kg/m$^2$. Fruits harvested from plots NPK-B, NPK-E and NPK-S had the lowest nutritional qualities and antioxidant properties. Sweet pepper plants sprayed with K-optimal or from farmers contained lambda-cyhalothrin at concentration of 0.0199 in pot experiment and 0.19 mg/kg under field experiments. These results showed that organic treatments, improved the fruit quality with no traces of pesticide residues and the antioxidant properties of fruits. Therefore, they could be used to control malnutrition, diseases such as cardiovascular diseases and enhance the mechanism of calcification and skeletal integrity. The aqueous extract of *O.gratissimum* and cassava peels compost at 2kg: 3kg (compost /soil) and 6kg: 2.40m$^{-2}$ can be used as alternative solution to conventional synthetic pesticide and fertilizer for sustainable agriculture.



**Keywords:** Organic fertilizer, *Ocimum.gratissimum*, Sweet pepper, Antioxidant, Essential minerals, Malnutrition.

## RESUME

Ce travail a été réalisé pour évaluer l'effet de l'utilisation combinée d'extrait aqueux du basilic (*Ocimum gratissimum*) et de compost produit à base des peaux de manioc (CP) sur le rendement, la teneur en nutriments, les propriétés organoleptiques et antioxydantes du poivron (*Capsicum annuum* L.).. Comme résultats, selon l'enquête menée, les variétés de poivrons les plus cultivées par les agriculteurs étaient «Yolo wonder » et «Simba ». 89 % des cultivateurs de poivron possédaient un champ de poivrons d'une superficie comprise entre 0,5 et 1 hectare. La cyperméthrine et le mancozèbe représentaient respectivement 63 % et 85 % des principes actifs utilisés par les cultivateurs pour lutter contre les maladies du poivron. Après trois mois de compostage, les composts produits avaient une couleur brun foncée, une structure relativement sèche et uniforme et leurs textures étaient similaires à celle du sol et leur pH légèrement acide (6,50-6,73), approprié pour la culture du poivron. Les rapports C/N des composts étaient compris entre 13,15 et 13,42. Les composts ont montré un indice de germination et un pourcentage d'émergence supérieurs à 80%, indiquant l'absence de phytotoxicité. Douze traitements (CP1-B, CP1-E, CP1-S, CP2-B, CP2-E, CP2-S, NPK-B, NPK-E, NPK-S, C-B, C-E et C-S) ont été appliqués aux expérimentations en pots et en champ. Les expériences en pots et en champ ce sont déroulées en parcelles divisées (split-plot). CP1-B et CP2-B ont positivement et significativement augmenté le temps de conservation des fruits de 70 jours à 90 jours à $4^0$C et de 23 jours à 26 jours à température ambiante, les propriétés organoleptiques, les qualités nutritionnelles des fruits et les propriétés antioxydantes par rapport aux traitements conventionnels. Les fruits issus des traitements organiques ont présenté les meilleures valeurs des rapports Na/K et Ca/P, illustrant de bons indicateurs de leurs valeurs nutritionnelles. Le traitement CP2-B a augmenté le rendement de 93 % dans les expériences en pots et de 187 % dans les expériences en champ comparativement au traitement NPK-B qui avait un rendement de 6 kg/m$^2$ en champ et 4 kg/m$^2$ en pots. Les fruits pulvérisées avec K-optimal ou provenant des agriculteurs étaient riches en lambda-cyhalothrin à une concentration de 0,0199 en pots et de 0,19 mg/kg en champ. Ces résultats ont montré que les traitements organiques ont amélioré la qualité des fruits sans traces de résidus de pesticides et les propriétés antioxydantes des fruits. Par conséquent, ils pourraient être utilisés pour contrôler la malnutrition, des maladies telles que les maladies cardiovasculaires et améliorer le mécanisme de calcification et l'intégrité du squelette. L'extrait aqueux d'*O.gratissimum* et de compost de peau de manioc (2kg de compost par 3kg de sol et 6kg de compost par 2.40m$^{-2}$) peuvent être utilisé comme solution alternative aux pesticides et engrais de synthèse conventionnels pour une agriculture durable.



**Mots clés** : Engrais organique, *Ocimum.gratissimum*, Poivron, Antioxydant, Minéraux essentiels, Malnutrition.

# GENERAL INTRODUCTION

Malnutrition is the consequence of disease, poverty, hunger, war, and natural catastrophe and greater than 1 billion of the world's population suffered from malnutrition (Cederholm *et al*., 2019). In Africa, the estimated number of undernourished people increased to 821 million (10.9%) in 2017, up from 784 million (10.6%) in 2015. In 2017 worldwide, it affected 151 million children (22.2%) and 51 million children under five (7.5%) suffered from wasting (Galani *et al.,* 2020). Malnutrition is micronutrient deficiencies that have been identified as major public health problems affecting a large part of the world's population (Manjeru *et al*., 2019). There are many pregnant women worldwide and children under 5 years at the highest risk (Galani *et al*., 2020b). On the other hand, many other illnesses are known to be associated with malnutrition, such as stroke, Parkinson's disease and diseases of the mouth and throat (Wells *et al*., 2003 and Suominen *et al*., 2005). The main consequence of malnutrition is the deficiencies in the minerals calcium, iodine, iron, selenium, zinc, and vitamins such as folate and vitamin A (WHO and UNICEF, 2017 and Galani *et al*., 2020b). Therefore, micronutrients play important roles in human health and can retard growth and cognitive development, impair immunological functioning and increase the risk of non-communicable diseases including skeletal, cardiovascular and metabolic disorders (WHO/FAO, 2003), Fairweather-Tait *et al*., 2011; Galani *et al.,* 2020). Moreover, It was reported that about half of all anemia is attributable to iron deficiency depending on the geographic and disease environment (Darnton-Hill and Mkparu 2015).

One of the principal means to reduce malnutrition could be the increase in food intake and the cultivation of fruits and vegetables that are rich in micro and macronutrients. Among those fruits and vegetables, there are beans, tomato, okra, carrot, eggplant, chilli, pepper (Dhaliwal *et al.*, 2017), including sweet pepper. Sweet pepper (*Capsicum annuum. L*) is a spice plant native to South America. It is cultivated in almost every country in the world. In 2016, the global production of sweet pepper reached 34497460 tonnes (FAOSTAT, 2018) and in West Africa 1,072,000 tonnes of fruits. It is widely distributed throughout the world and is an important source of incomes, particularly in peri-urban agriculture. Sweet peppers are generally rich in carotene (precursor of vitamin A) and vitamin C. It also contains vitamins PP, B1 and B2 as well as mineral elements such as calcium and iron. Therefore, a good ingredient to control malnutrition and metabolic diseases. Like most tropical crops, peppers are affected by many

viral diseases, among them, the green variegation of peppers which is one of the most important particularly in West Africa, (Meghwal *et al.,* 2011). It also faces fungal diseases namely: *Colletotrichum spp and Phytophthora capsici*, (Dagnoko *et al*., 2013); bacteria (*Erwinia carotovora subsp, Carotovora and Xanthomonas campestris pv. vesicatoria*), (Dagnoko *et al*., 2013) and pests (aphids, fruit flies and moths), (Dagnoko *et al*., 2013), which can affect 50 to 100% of plants in fields (FAO, 2018). Besides, its cultivation requires a soil rich in organic matter. In Cameroon, various field surveys have revealed that pepper cultivation is affected with several major constraints such as (i) fruit drop before maturity, due to flies attacks (*Ceratitis spp., Bactrocera spp*., Etc.), (ii) Fusarium attack causing a fungal disease characterized by senescence followed by the sudden death of the whole pepper plant and (iii) a viral disease transmitted by whiteflies (*Bemisia tabaci*) characterized by leaf discolouration leading to severe leaf distortions or an irreversible plant growth retardation. Those constraints are present in all pepper production zones in Cameroon and are also responsible for significant yield losses (Segnou *et al.,* 2013). Therefore, this does not allow farmers to significantly contribute in the fight against nutrition problems in the world and more specifically in Africa, which are responsible for certain metabolic and chronic diseases such as cancer, asthma, cough, diabetes and cardiovascular diseases (El-Ghoraba *et al*., 2013 and Wahyuni *et al*., 2019). To solve this problem, farmers around the world and in Africa use excessively mineral fertilizers and synthetic pesticides for pests and diseases control (Savci, 2012, Sharma *et al.,* 2017 and Kumar *et al.,* 2019) not only to increase crop yields but also to control pathogens. This is the case of Cameroonian farmers, who have also resorted to the use of certain pesticides in the cultivation of peppers such as: insecticides (cypercal 50 EC; active ingredient: 50 g / l of cypermethrin), fungicides (trimangol 80 WP (wettable powder); active ingredient: 800 g / kg of mancozeb) and a combination of these two chemicals (cypercal 50 EC + trimangol 80 WP), (Segnou *et al*., 2013).

However, the above solutions have shortcomings such as (1) the accumulation of heavy metals and pesticide residues, environmental pollution (water, soil and atmosphere), (2) the appearance and generalization of resistance mechanisms in pathogens, (3) ecological imbalance since many of these synthetic compounds have a broad spectrum of action, destroying not only harmful agents, but also other useful microorganisms of the ecosystem (4) intoxication of farmers and consumers and (5) problems of postharvest conservation of agricultural products, (Akram, 2008; Brühl *et al*., 2019; Mancini *et al*., 2019, Galani *et al.,* 2020).

Therefore**,** it is important to find alternative solutions such as new and effective means of disease control and soil fertilization, which present a lower risk on human health and environment. This will help to fight against phytopathogens, avoidance of crop rotation, fallow and soil pollution while reducing the utilization of synthetic chemicals.

This will concern the usage and development of biopesticides (Akram, 2008), more specifically the management of diseases using biopesticides such as products derived from plants and antagonistic microorganisms (Olanya *et al.*, 2006); the use of bio-inputs by revalorizing urban and rural waste through composting since more than 75% of the waste produced in African cities like the city of Yaoundé that is made up of organic materials (Ngnikam and Tanawa 2006). Moreover, many types of compost suppress soil-borne plant diseases (Tita *et al*., 2015).

## Research hypotheses

The research hypotheses relate to the specific objectives of this project, which is the combined use of *Ocimum gratissimum* aqueous extract and compost made from cassava peels: Increase the yield and the shelf life of harvested sweet pepper fruits; improve the nutritional, organoleptic and biological quality of sweet peppers and reduce the content of pesticide residues; inrich the microflora, increase soil fertility and productivity, protect the environment, consumers and the farmer against chemical pollution and poisoning.

## General objective

The general objective of this work was to evaluate the combined use of a biopesticide and compost on yield, nutrient content, organoleptic and antioxidant properties of sweet pepper fruits and soil physicochemeical and biological properties.

## Specific objectives

- Survey the cultural practices and diseases management of sweet pepper at the locality of Foumbot, west region of Cameroon and the quality of cassava peels compost and its impact on soil quality.
- Study the effect of the combined use of acqueous extract of *Ocimum gratissimum* leaves and composts on the productivity of sweet pepper and compare the shelf life of sweet peppers'fruits obtained from soil amended by bio-inputs and a conventional fertilizer.
- Evaluate the treatments effect on the organoleptic, nutritional, antioxidant properties and pesticide residues of the harvested fruits.

# CHAPTER I: LITERATURE REVIEW

# CHAPTER I: LITERATURE REVIEW

## I.1 Generality on sweet pepper

Sweet peppers (*Capsicum annuum L.*) originate from central and South America where numerous species were used centuries before Columbus landed on the continent (Manrique, 1993). The cultivation of peppers, spread throughout Europe and Asia after the 1500s. Although perennials, they grow as annuals in temperate climates. The cultivation of sweet peppers is sensitive to low temperatures and is relatively slow to establish (Department of Agriculture, Forestry and Fisheries, 2013).

### I.1.1 Classification

The scientific name of sweet pepper is *Capsicum annuum* and the common names are bell pepper and sweet pepper. In actual sense, *Capsicum* is a genus with five domesticated species including (Negi *et al.*, 2018):

*Capsicum annuum L*. (origin Mexico), having a toothed calyx.
*Capsicum frutescens L*. (origin Amazonia), having a greenish flower and non-toothed calyx.
*Capsicum chinense* (origin Amazonia), having a constricted toothed calyx.
*Capsicum baccatum L*. (origin Amazonia), having a corolla with yellow/brown spots.
*Capsicum pubescens* (origin Peru and Bolivia), having black colored seeds and purple flowers.
The below table 1 presents the botanical classification.

**Table 1: Botanical classification of *Capsicum annuum***

| **Kingdom** | **Plantae** |
|---|---|
| **Division** | Magnoliophyta |
| **Class** | Magnoliopsida |
| **Order** | Solanales |
| **Family** | Solanaceae |
| **Genus** | *Capsicum* |
| **Species** | ***Capsicum Annum L*** |
| **Botanical varieties** | ***var. glabriusculum(synonym var. aviculare)*** <br> ***var. annuum*** |

### I.1.2 Description of the plant

Sweet peppers are green at first and change to red, yellow or purple. They contain many flat, kidney-shaped, white seeds. When the fruit is ripe it is red or yellow, but it is used as a vegetable in the green stage. Although these plants are technically perennials, they are not worth keeping after fruiting once. It is better to start new plants every year. Greenhouse production of peppers is based on indeterminate cultivars in which the plants continually develop and grow from new meristems that produce new stems, leaves, flowers and fruit. In comparison, field pepper cultivars are determinate; the plant grows to a certain size, produces fruit and stops growing and eventually dies off. Indeterminate cultivars require constant pruning to manage their growth. In order to optimise yield, a balance between vegetal (leaves and stems) and generative (flowers and fruits) growth must be established and maintained. (Department of Agriculture, Forestry and Fisheries, 2013).

### I.1.3 Roots, stem, leaves, flowers and fruit

By the end of the season, the pepper's roots may extend 20 to 30 cm deep and at least as wide, but they remain fairly fine. Pepper's roots are deeper than those of lettuce, broccoli or spinach; however, they remain fairly close to the surface. There are many different varieties of peppers ranging from 30 to 90 cm tall. Pepper leaves are oval and taper to a point. They are usually bright to dark green, but can also be mottled. The size of the leaf corresponds somewhat to the size of the fruit; plants that produce very small peppers also tend to have small leaves, while the larger bell pepper cultivars have large, broad leaves (Department of Agriculture, Forestry and Fisheries, 2013).

They have straight, woody stems and single, star-shaped, white flowers in the axils of the leaves. The flowers are followed by juiceless berries or pods, which vary in shape and size. When ripe, the fruit is red, yellow or brown but immature fruit of the large mild types are often picked while still green for use in salads. These species generally bear large fruits.

### I.1.4 Cultivation practices

Most sweet pepper that are frequently grown are varieties of *C. frutescens*, which are the peppers grown in the vegetable garden. There are many varieties of garden peppers. They are divided into two groups; the sweet peppers or mild-flavoured varieties, which are used for stuffing, salads and garnishing; and the hot peppers, which are mainly used in sauces and flavouring. *C. frutescens* grossum, the sweet or bell pepper, is a popular vegetable. Certain

types of peppers are very pretty when grown as potted plants, especially in the fall and early winter. The best are C. frutescens cerasiforme, the cherry pepper and C. frutescens conoides, the cone pepper. The varieties of these kinds have red, purple or cream-coloured fruit displayed above the rich green foliage. (Department of Agriculture, Forestry and Fisheries, 2013).

### I.1.5 Cultivar selection

Bell pepper cultivars differ in such horticultural traits as fruit size, shape (e.g. blocky versus elongated), number of lobes, flavour, and disease resistance. Standard green bell cultivars typically ripen to red; however, specialty bell peppers include cultivars that ripen to a colour other than red. These specialty bells may be yellow, orange, brown, white, and even purple at maturity. Compared to green bell peppers, coloured bells are often more difficult and expensive to produce because a longer time to reach maturity is required. Growers should only select adapted varieties that have the qualities in demand for the intended market. Owing to the prevalence of bacterial leaf spot in Kentucky, only hybrid varieties with leaf spot resistance are recommended for commercial production. While resistance to bacterial leaf spot has helped reduce losses because of this devastating disease, new races of the pathogen have been isolated to which there is currently no resistance. (Department of Agriculture, Forestry and Fisheries, 2013).

### I.1.6 Climatic requirements

#### I.1.6.1 Temperature

Sweet pepper is a warm-season crop, which performs well under an extended frost-free season, with the potential of producing high yields of outstanding quality. It is very vulnerable to frost and grows poorly at temperatures between 5 and 15 °C (Bosland and Votava, 1999). The optimum temperature range for sweet pepper growth is 20 to 25 °C (Anon, 2000).

The germination of pepper seed is slow if sown too early when soil temperatures are still too low, but seedling emergence accelerates as temperatures increase to between 24 and 30 °C (Bosland and Votava, 1999). The optimum soil temperature for germination is 29 °C (Anon, 2000). Low temperatures also slow down seedling growth, which leads to prolonged seedling exposure to insects, diseases, salt or soil crusting, any of which can severely damage or kill off the seedlings (Bosland and Votava, 1999).

High temperatures adversely affect the productivity of many plant species including green pepper. Sweet pepper requires optimum day/night temperatures of 25/21 °C during flowering.

The exposure of flowers to temperatures as high as 33 °C for longer than 120 hours leads to flower abscission and reduced yields. Pollen exposed to high temperatures (>33 °C) normally becomes non-viable and appears to be deformed, empty and clumped (Erickson & Markhart, 2002). Temperatures lower than 16 °C can lead to fruitless plants (Coertze and Kistner, 1994).

Higher yields are obtained when daily air temperature ranges between 18 and 32 °C during fruit set (Bosland and Votava, 1999). Persistent high relative humidity and temperatures above 35 °C reduce fruit set. Fruit that is formed during high-temperature conditions is normally deformed. Sweet peppers are also very sensitive to sunscald (Coertze and Kistner, 1994a). Fruit colour development is hastened by temperatures above 21°C (Bosland & Votava, 1999).

### I.1.7 Soil requirements

Sweet peppers prefer deep, fertile, well-drained soils. Avoid planting in lowlying fields next to streams and rivers because these sites are subject to high humidity and moisture conditions and, therefore, especially prone to bacterial spot epidemics. Producers should also avoid fields where longresidual corn or soya bean herbicides have been used, because herbicide carry-over can cause serious damage to peppers. (Department of Agriculture, Forestry and Fisheries, 2013). Pepper fields should be located as far away from tobacco plantings as possible owing to potential spread of aphid-vectored viruses from tobacco to peppers. It is also advisable not to grow peppers after other solanaceous crops (such as tobacco, tomatoes, potatoes, and brinjals) or vine crops for a period of three years because all of these crops are susceptible to some of the same diseases. Peppers do extremely well following fescue sod. Use a soil test to determine fertiliser and liming requirements. Peppers grow best at soil pH between 6,0 and 7,0. Adjust the soil pH to near neutral (7,0) for maximum yields. To reduce the risk of Verticillium wilt and other diseases, avoid using fields in your rotation plans in which eggplant, tomato, pepper, potato and strawberry or caneberry have been planted. (Department of Agriculture, Forestry and Fisheries, 2013).

#### I.1.7.1 Soil preparation

More important than fallowing in particular rotation over many years is the precaution to avoid growing peppers on the same soil more often than once in 3 or 4 years. Peppers are subject to some of the same diseases, neither should follow the other in successive seasons in the same

soil. Soil used for plant beds should have had no peppers grown in it for 4 or 5 years, preferably never before. (Department of Agriculture, Forestry and Fisheries, 2013).

### I.1.8 Days to maturity

The exact time to maturity varies depending on the exact variety of bell pepper. Most sweet peppers mature in 60 to 90 days after planting. However, the number of days to maturity stated on the seed packet refers to the days after transplanting until the plant produces a full-sized fruit.

### I.1.9 Harvesting methods and recommendations

Peppers are generally broken off from the plants with the stems left attached to the fruit. For sweet peppers strong cloth picking bags, which are suspended from the shoulders of the pickers, are preferable to baskets or boxes. This frees both hands for rapid and careful removal of the fruit from the plants. Hard picking containers may become rough and sandy, and as a result cause damage to the peppers. (Department of Agriculture, Forestry and Fisheries, 2013). Pepper fruit is later carried to a central point where it is graded and packed into standard baskets or put into containers for delivery to the market or processing plant. The red-ripe peppers are sometimes sun dried and stored in bags. Care should be taken when breaking the peppers from the plants, as the branches are often brittle. Hand clippers or pruners can be used to cut peppers from the plant to avoid excessive stem breakage. The number of peppers per plant varies with the variety. Bell pepper plants may produce six to eight or more fruit per plant. (Department of Agriculture, Forestry and Fisheries, 2013).

Bell peppers are harvested when they are immature and green, but when they have reached full size and maximum wall thickness. Each field is harvested multiple times by hand. Some are picked after they have ripened to red or other colours. Peppers destined for wholesale shipment are usually washed, sorted and graded on a packing line.

### I.1.10 Consumption and nutritional value of sweet peppers

Sweet pepper is a good source of natural antioxidants, containing many different antioxidant components that provide protection against free radicals and are associated with health-promoting properties. These beneficial effects have been related to the presence of some

vitamins such as vitamin C, dietary fibre and other phytochemicals (polyphenols) in this plant food product (AJ .Pérez –Lopez *et al.,* 2007). Sweet peppers are consumed due their taste and to the presence of compounds that prevent some diseases (Elisa Helena da Costa Morais *et al.,* 2018). Unlike other chilli peppers, it is very low in calories and fats: 100 g provide only 31 Calories. Peppers are popular vegetables because of their colour, taste and nutritional value. Fresh peppers have a high content of vitamin C and are a good source of provitamin A carotenoids. One medium sweet pepper can provide up to 8% of the recommended daily allowance of Vitamin A, 180% of Vitamin C, 2% of calcium and 2% of iron (Kelley WT. Boyhan G, 2009). Sweet pepper fruits contain three to six times as much vitamin C as an orange (Bosland and Votava, 2007).

Ascorbic acid is a required human nutrient and its biological functions are centred on its antioxidant properties in biological systems, preventing common degenerative processes.The importance of carotenoids in the diet has been recognised, as vitamin A precursors and antioxidants in cell protection, for the prevention of degenerative diseases and for human epithelial cell differentiation (Pérez –Lopez *et al.,* 2007). Moreover, carotenoid pigments are responsible for the red colour of peppers. Peppers also contain moderate to high levels of phenolics, phytochemicals that are important antioxidant components of plant food products and may reduce the risk of degenerative diseases. (Pérez –Lopez *et al*., 2007).

Early laboratory studies on experimental mammals suggest that sweet pepper's capsaicin has anti-bacterial, anti-carcinogenic, analgesic and anti-diabetic properties. When used judiciously, it is also found to reduce triglycerides and LDL cholesterol levels in obese individuals. Its regular consumption prevents the accumulation of the fat mass of the body (Bosland and Votava, 2007). It promotes learning and fights against the deficits of the memory related to the age. (Bosland and Votava, 2007).

Sweet pepper is consumed both in green mature and ripe form, raw in salads, cooked, mixed and stuffed vegetable. It is widely used in the preparations of pickles, sauces, soups and stews. Ascorbic acid present in it aid in prevention of certain types of cancer, cardiovascular diseases, stroke, and cataracts. It helps to normalize blood pressure levels. It controls blood pressure and prevents cancer. The rich vitamin C content present in it mainly prevents Blood Clotting (Radhika Negi *et al*., 2018).

### I.1.11 Antioxidants potential of sweet Pepper

Antioxidants work to protect lipids from peroxidation by radicals. They inhibit or delay the oxidation of other molecules by inhibiting the initiation or propagation of oxidizing chain reactions. Antioxidants are effective because they are willing to give up their own electrons to free radicals. When a free radical gains the electron from an antioxidant it no longer needs to attack the cell and the chain reaction of oxidation is broken (Muhammad Nadeem *et al.*, 2011). There are two basic categories of antioxidants, namely, synthetic and natural. In general, synthetic antioxidants are compounds with phenolic structures of various degrees of alkyl substitution, whereas natural antioxidants of plant region are classified as vitamins, phenolic compounds, or flavonoids (El-Ghorab *et al*., 2007).

Antioxidants protect the food or body from oxidative damage induced by free radicals and reactive oxygen species by (1) suppressing their formation; (2) acting as scavengers; and (3) acting as their substrate. Synthetic antioxidants such as butylated hydroxyanisole (BHA) and butylated hydroxytoluene (BHT) have been used as antioxidants since the beginning of this century. Restrictions on the use of these compounds, however, are being imposed because of their carcinogenicity (Ito *et al*., 1983).

Vitamin C is considered among the most potent chain breaking antioxidant within the membrane of the cell. Inside the cell water soluble antioxidant scavengers are present. These include glutathione peroxidase, superoxide dismutase (SD), and catalase (Dekkers *et al*., 1996). Natural antioxidants are extensively studied for their capacity to protect organism and cells from damage induced by oxidative stress (Dastmalchi *et al*., 2008).

However, Cultivars and growing conditions seem to play an important role in affecting the metabolism of antioxidant components and antioxidant capacity. Sweet pepper (*Capsicum annuum L*.) is a vegetable known for its rich antioxidant content. Fresh sweet peppers have exceptionally high ascorbic acid, a 100 g serving supplying 100% of the current recommended dietary allowance (RDA) of 60 mg/ day (Simmone *et al*., 1997).

Sweet peppers, among vegetables, have become extremely popular for the abundance and the kind of antioxidants they contain. Among the antioxidant phytochemicals, polyphenols deserve a special mention due to their free radical scavenging properties. These compounds whose levels vary strongly during growth and maturation are also important because of their contribution to pungency, bitterness, colour and flavour of fruits (Estrada *et al*., 2000).

### I.1.12 Sweet pepper production in Cameroon

Exact statistics of pepper production are not available in Cameroon but within the South-West region of Cameroon the consumption is 3005t for a surface area of 2226 ha and the exportation of sweet pepper is 5,9t. (MINADER /Agri -start July, 2012). It is really recognised that the market price, which vary in between 450 and 700 per kg in 2012 (Temgoua Emile *et al*., 2012), of this spice is constant on the rise (Djieto-Lordon *et al.,* 2014). This growth is attributed to the high demand from the Cameroon urban areas. In Yaoundé and other towns of Cameroon such as Foumbot; etc, sweet peppers (*Capsicum annuum*) appear among the most current spice species. They are consumed in various culinary preparations: fresh, dried or used for salads, in association with other vegetables. As a consequence of extreme increase in local consumption of pepper, cultivators are increasing their pepper growing areas. However, this tasty spice is mainly attacked by many pest insects and diseases which reduce their fitness and production. Few reports and Masters Dissertations have been conducted to identify the insect pests and diseases of *Capsicum annuum* in Cameroon (DjietoLordon *et al*., 2002; Elono Azang *et al*., 2007; Djieto-lordon *et al.,* 2014).

According to Okolle *et al.,* (2014) sweet pepper cultivation is an important element in the fight against poverty. It is also a major spice and vegetable widely consumed by the majority of the population locally and regionally in Cameroon.

Sweet pepper is one of the most popular and highly priced annual herbaceous vegetable crops in Cameroon. The crop has helped in poverty alleviation by the farmers engage in the business through the sale of the fruit on the local market and export, which has therefore increased the farmer's income. Sweet pepper's fruits consumption in Cameroon is growing recently because of increasing demand by urban consumers. There is a good demand for export more especially to the European and African market that earns the country with foreign exchange. Majority of pepper and other vegetable fields are located in rural communities and exploited mainly by male smallholder farmer which provides employment for the producers (AVRDC, 2008). Besides, women are the main marketers, processers, buyers, and users of these products (Yaméogo *et al*., 2002). Moreover, over 25 percent of the world's population consumes and utilizes peppers every day (Namiki, 1990) and since 2000, the world production and consumption of bell peppers have been steadily increasing (Biswas *et al.,* 2017).

## I.2 Soil fertilization

### I.2.1 Definition: Soil fertility and soil quality

#### I.2.1.1 Soil fertility

Soil fertility is defined as the ability of a soil to provide the conditions required for plant growth. It is a result of the physical, chemical and biological processes that act together to provide nutrients, water, aeration and stability to the plant (Stockdale *et al.*, 2002 ). According to the FAO, soil fertility is "the capacity of the soil to provide essential nutrients to plants, water in sufficient quantity and proportion for the growth and reproduction of plants, in the absence of toxic substances that can inhibit growth. According to (Watson *et al.*, 2002), Soil fertility is most commonly defined in terms of the ability of a soil to supply nutrients to crops. It is more helpful to view soil fertility as an ecosystem concept integrating the diverse soil functions, including nutrient supply, which promote plant production. This broader definition is appropriate to organic farming, as organic farming recognizes the complex relationships that exist between different system components and that the sustainability of the system is dependent upon the functioning of a whole integrated and inter-related system.

Koopmans and Smeding (2008) identify soil fertility (nutrients, structure and disease suppression), resistance and adaptations (resistance against stress and flexibility), buffer (organic matter, ability for self-cleaning, water retention and climate function) and biodiversity as soil services. Soil services are linked with the management practiced by the farmer. Soil management affects soil life (biodiversity) directly and soil with the presence of roots, on the other hand has an indirect effect. All the management lead to soil services which finally affect productivity and the time required to reach the effect.

#### I.2.1.2 Soil quality and indicators of soil fetility

The notion of soil quality is one of the three components of environmental quality alongside air and water quality. The most accepted definition of soil quality is "the capacity of the soil to function within ecological and land use limits, to sustain biological productivity, to maintain air quality and to promote animal and plant health" (Bünemann *et al*., 2018; Juhos *et al.*, 2015). There are several types of indicators for measuring the quality of a soil. They are divided into 3 groups taking into account the main functions of the soil, which are to ensure: water infiltration; water and nutrient storage, nutrient supply and cycling; maintenance of biological activities.

Among those indicators there is chemical, physical or microbiological type. The physical properties of soil are generally related to its ability to store and supply water to the plant. Physical indicators express the retention capacity, bulk density and texture of the soil. Chemical indicators take into account the capacity of the soil to store, supply and ensure nutrients cycle The most widely used chemical indicators are: organic carbon content, pH, available phosphorus and potassium, total nitrogen, electrical conductivity, cation exchange capacity and mineral nitrogen. The soil organic matter is among the most important indicators due the fact that it affects the physical, chemical and biological soil. Biological indicators define the ability of the soil to maintain biological activities. The main biological indicators are: soil respiration, microbial biomass, nitrogen mineralization and earthworm density (Bünemann *et al*., 2018; Giacometti *et al*., 2012; Lima *et al*., 2012).

### I.2.2 Soil organic matter and soil fertility

The term "Soil organic matter" (SOM) has been used in different ways to describe the organic constituents of soil. According to Baldock and Skjemstad (1999) it is "all organic materials found in soils irrespective of origin or state of decomposition". The SOM consists of C, H, O, N, P and S. The organic matter content of the most agricultural land is very closely related to its potential productivity, loosening and fertility. Indeed, it facilitates the aggregation of the soil and gives it structural stability which helps to improve air / water ratios and root growth, as well as to protect the soil from wind and hydraulic erosion. It is a source of nutrients for plants and, in combination with crop residues, provides soil microflora with carbon which stimulates nutrient recycling and beneficial changes in physical properties.

#### I.2.2.1 Principal functions of SOM in soils

In general, organic matter of the soil contribute to soil fertility in several quite distinct ways It helps to give a soil a good stable structure, which is particularly Important in the surface soil by its oxidation in the soil, plant nutrients such as nitrogen, phosphorus and sulphur are released in a form available for uptake by crop roots. It helps to increase the cation exchange capacity, so increase the ability of the soil to hold cations against leaching but in a form available to the crops (Russell, 1977). On soil containing appreciable amounts of active iron and aluminum hydroxides it may help to increase the availability of added phosphorus to the crop. A small part is soluble or disperse in the soil water: this part contains trace elements such as copper and iron in chelation, and some components of this fraction serve as important sources of these elements for the crop (Mercer and Richmond 1890, 1971, 1972)..

The functions of SOM can be classified into three groups: biological, physical and chemical (Figure1). These groups are not static entities and dynamic interactions occur between these three major components.

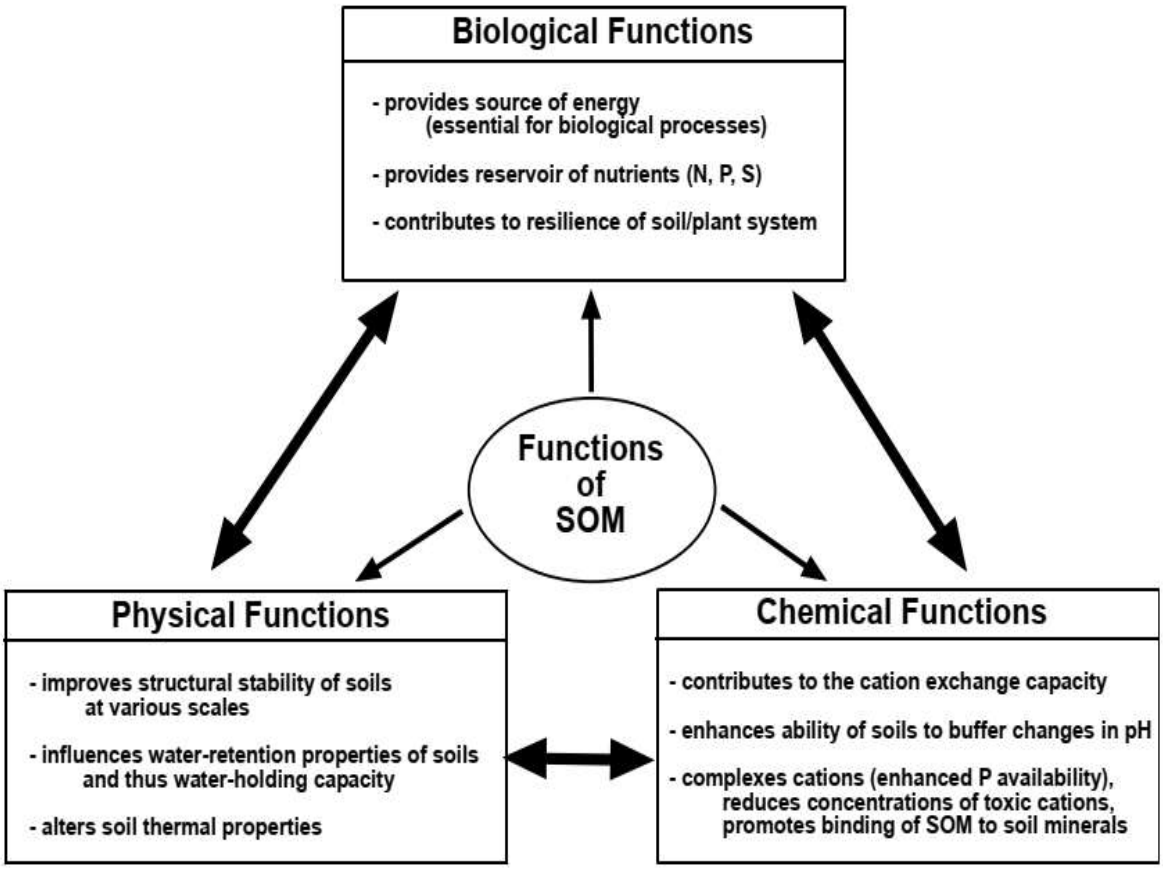



**Figure 1:** Functions ascribed to SOM. Note that interactions occur between the different soil functions modified from Baldock and Skjemstad, (1999).

### I.2.2.2 The role of SOM in soil fertility

The roles of SOM in improving soil productivity include: regulation of the rates and amounts of nutrients released for plant uptake in soils; improvement of soil water infi ltration rate and soil water-holding capacity; increasing cation exchange capacity, or the soil's capacity to store nutrients; ; enhancing soil aggregation (SOM particles act as binding agents), improving soil structure, reducing bulk density and promoting good aeration; and binding of toxic elements in soils and minimizing their impacts on growing plants (Fairhurst, 2012).

### I.2.3 Soil fertility management practices

#### I.2.3.1 Use of mineral fertilizers

Fertilizer is a material that contains at least one of the plant nutrients in chemical form that, when applied to the soil, is soluble in the soil solution phase and 'available' for plant roots. Some fertilizers such as urea, potassium chloride (KCl) and diammonium phosphate (DAP) are completely soluble in water, while others such as rock phosphate and dolomite are partly soluble and release nutrients slowly over several months or years. The objective of fertilizer use is to deliver nutrients to crop plants. As a guide, fertilizer materials should contain at least 5% of one or more of the essential nutrients in an immediately available form. (Fairhurst, 2012) The nutrient content of proper mineral fertilizers is always stated on the bag label. The P, potassium (K) and magnesium (Mg) content is expressed in the oxide form, i.e. $P_2O_5$, $K_2O$ and MgO. Secondary and micronutrients are often included in compound fertilizers (Fairhurst, 2012).

#### I.2.3.2 Use of organic inputs

Organic inputs used in soil fertility management commonly consist of livestock manures (farmyard manure), crop residues, woodland litter, household organic refuse, composted plant materials (compost), and any plant biomass harvested from within or outside the farm environment for purposes of improving soil productivity. In urban and peri-urban areas, organic inputs can also be made up of industrial organic waste and sewage sludge. (Fairhurst, 2012).

Organic resources have multiple functions in soil, ranging from their influence on nutrient availability to modification of the soil environment in which plants grow. Organic inputs derived from plant remains provide most of the essential nutrient elements, but usually insufficient quantities (Fairhurst, 2012). Because of their richness in carbon, organic resources provide an energy source for soil microorganisms which drive the various soil biological processes that enhance nutrient transformation and other quality parameters of soil (Fairhurst, 2012).

As these organic materials undergo the process of decomposition in soil, they contribute to the formation of soil organic matter (SOM), which is generally considered to be the backbone of soil fertility. (Fairhurst, 2012) Most of the lasting impacts of organic inputs on soils are related to the functions of SOM. During decomposition, the organic materials interact with soil minerals forming complex substances that influence nutrient availability (e.g. binding of

otherwise toxic chemical substances such as aluminium or leading to better release of phosphorus bound to soil mineral surfaces) (Fairhurst, 2012).

### I.2.3.3 Organics as sources of nutrients

The role of organic materials as nutrient sources is underpinned by the biological processes of decomposition, which involve the biochemical breakdown of dead organic tissue into its inorganic constituent forms, primarily through the action of microorganisms. (Fairhurst, 2012) The process by which essential nutrient elements in unavailable organic forms are converted into their inorganic forms that are available for use by growing plants is known as mineralization. It is during decomposition of organic materials in soils that SOM is formed and nutrients are released. SOM can therefore said to be made up of organic materials of diverse origin that are at various stages of decomposition through the action of soil microorganisms (Fairhurst, 2012).

Soil organic matter is a significant source of nitrogen (N), phosphorus (P) and sulfur (S) in crop production. The supply of these nutrients from SOM is dependent upon a number of factors including (Fairhurst, 2012):

- the quantity and frequency with which organic inputs are added to the soil;
- the quality of the organic resources; and
- the effect of soil type (e.g. texture and mineralogy) and environmental conditions (e.g. moisture and temperature) that provide an environment in which the processes of decomposition and mineralization occur.

## I.3 Composting

Composting, considered as an environmental-friendly process, involving aerobic transformation of organic matter and destruction of pathogens and weeds (Rawoteea *et al*., 2017; Wu *et al*., 2017). This process is regarded as a great contributor of promoting circular agriculture (Cáceres *et al*., 2017) because allows stabilization of organic waste and production of an organic fertilizer that can be used as a soil conditioner (Sun *et al*., 2016), in gardening or as a growing medium in soilless cultures. A model of organic waste management, based on the production and use of high quality composts, is urged for contributing to mitigate the release of carbon into the atmosphere (Silva *et al*., 2009 and Cáceres R *et al.,* 2018).

### I.3.1 Composting methods

#### I.3.1.1 Traditional methods

##### I.3.1.1.1 Anaerobic composting

**Indian Bangalore method**

Indian Bangalore method was developed at Bangalore in India in 1939 (FAO, 1980). It is recommended where night soil and refuse are used for preparing the compost. The method overcomes many of the disadvantages of the Indore method (below), such as the problem of heap protection from adverse weather, nutrient losses from high winds and strong sun, frequent turning requirements, and fly nuisance. However, the time required for the production of finished compost is much longer. The method is suitable for areas with scanty rainfall (FAO, 2003).

**Pit preparation**

Trenches or pits about 1 m deep are dug; the breadth and length of the trenches can vary according to the availability of land and the type of material to be composted. Site selection is as per the Indore method. The trenches should have sloping walls and a floor with a 90–cm slope to prevent waterlogging (FAO, 2003).

**Filling the pit**

Organic residues and night soil are put in alternate layers. After filling, the pit is covered with a layer of refuse of 15–20 cm. The materials are allowed to remain in the pit without turning and watering for three months. During this period, the material settles owing to reduction in biomass volume. Additional night soil and refuse are placed on top in alternate layers and plastered or covered with mud or earth to prevent loss of moisture and breeding of flies. After the initial aerobic composting (about eight to ten days), the material undergoes anaerobic decomposition at a very slow rate. It takes about six to eight months to obtain the finished product (FAO, 2003).

**Passive composting of manure piles**

Passive composting involves stacking the materials in piles to decompose over a long time with little agitation and management (FAO, 2003). The process has been used for composting animal wastes. However, the simple placing of manure in a pile does not satisfy the requirements for continuous aerobic composting. Without considerable bedding material, the moisture content

of manure exceeds the level that enables an open porous structure to exist in the pile. Little if any air passes through it. Under these circumstances, the anaerobic micro-organisms dominate the degradation. All of the undesirable effects associated with anaerobic degradation occur (FAO, 2003).

Where a livestock management system relies on bedding to add to livestock comfort and cleanliness, the bedding becomes mixed with the manure and creates a drier, more porous mixture (FAO, 2003).

This provides some structure and, depending on the amount of bedding, enables the mixture to be stacked in true piles. The bedding also tends to raise the C:N ratio of the manure. A mixture of manure and bedding requires a considerable proportion of bedding to provide the porosity necessary for composting. At least equal volumes of bedding and manure are required. Where the amount of bedding is insufficient to provide a porous mix, additional dry amendments must be provided by either increasing the bedding used in the barn or adding amendments when piles are formed. Manure from horse stables or bedded manure packs (animal bedding and manure mixture) can often compost in piles alone, whereas non-bedded manure from dairy, swine and many poultry barns needs drying or additional amendments. The pile must be small enough to allow passive air movement, generally less than 2 m high and 4 m wide. This passive method of composting is essentially wind-row composting but with a much less frequent turning schedule. It is a common method for composting leaves. It demands minimal labour and equipment. Passive composting is slow because of its low aeration rate, and the potential for odour problems is greater (FAO, 2003).

#### I.3.1.1.2. Aerobic composting through passive aeration

#### Indian Coimbatore method

This method (Manickam, 1967) involves digging a pit (360 cm long × 180 cm wide × 90 cm deep) in a shaded area (length can vary according to the volume of waste materials available). Farm wastes such as straw, vegetable refuse, weeds and leaves are spread to a thickness of 15–20 cm. Wet animal dung is spread over this layer to a thickness of 5 cm. Water is sprinkled to moisten the material (50–60 percent of mass). This procedure is repeated until the whole mass reaches a height of 60 cm above ground. It is then plastered with mud, and anaerobic decomposition commences. In four weeks, the mass becomes reduced and the heap flattens. The mud plaster is removed and the entire mass is turned. Aerobic decomposition commences

in at this stage. Water is sprinkled to keep the material moist. The compost is ready for use after four months (FAO, 2003).

**Indian Indore pit method**

An important advance in the practice of composting was made at Indore in India by Howard in the mid-1920s. The traditional procedure was systematized into a method of composting now known as the Indore method (FAO, 1980 and FAO, 2003).

Raw materials

The raw materials used are mixed plant residues, animal dung and urine, earth, wood ash and water. All organic material wastes available on a farm, such as weeds, stalks, stems, fallen leaves, prunings, chaff and fodder leftovers, are collected and stacked in a pile. Hard woody material such as cotton and pigeon-pea stalks and stubble are first spread on the farm road and crushed under vehicles such as tractors or bullock carts before being piled. Such hard materials should not exceed 10 percent of the total plant residues. Green materials, which are soft and succulent, are allowed to wilt for two to three days in order to remove excess moisture before stacking; they tend to pack closely when stacked in the fresh state. The mixture of different kinds of organic material residues ensures a more efficient decomposition. While stacking, each type of material is spread in layers about 15 cm thick until the heap is about 1.5 m high. The heap is then cut into vertical slices and about 20–25 kg are put under the feet of cattle in the shed as bedding for the night. The next morning, the bedding, along with the dung and urine and urine-earth, is taken to the pits where the composting is to be done (FAO, 2003).

Pit site and size

The site of the compost pit should be at a level high enough to prevent rainwater from entering in the monsoon season; it should be near the cattle shed and a water source. A temporary shed may be constructed over it to protect the compost from heavy rainfall. The pit should be about 1 m deep, 1.5–2 m wide, and of a suitable length (FAO, 2003).

Filling the pit

The material brought from the cattle shed is spread in the pit in even layers of 10–15 cm. A slurry made from 4.5 kg of dung, 3.5 kg of urine-earth and 4.5 kg of inoculum from a 15–day–old composting pit is spread on each layer. Sufficient water is sprinkled over the material in the pit to wet it. The pit is filled in this way, layer by layer, and it should not take longer than one week to fill. Care should be taken to avoid compacting the material in any way (FAO, 2003).

Turning

The material is turned three times while in the pit during the whole period of composting: the first time 15 days after filling the pit; the second after another 15 days; and the third after another month. At each turning, the material is mixed thoroughly and moistened with water (FAO, 2003).

**Indian Indore heap method**

Heap site and size

During rainy seasons or in regions with heavy rainfall, the compost may be prepared in heaps above ground and protected by a shed. The pile is about 2 m wide at the base, 1.5 m high and 2 m long. The sides taper so that the top is about 0.5 m narrower than the base. A small bund is sometimes built around the pile to protect it from wind, which tends to dry the heap (FAO, 2003).

Forming the heap

The heap is usually started with a 20 cm layer of carbonaceous material such as leaves, hay, straw, sawdust, wood chips and chopped corn stalks. This is covered with 10 cm of nitrogenous material such as fresh grass, weeds or garden plant residues, fresh or dry manure or digested sewage sludge. The pattern of 20 cm of carbonaceous material and 10 cm of nitrogenous material is repeated until the pile is 1.5 m high and the material is normally wetted until it feels damp but not soggy. The pile is sometimes covered with soil or hay to retain heat and it is turned at intervals of 6 and 12 weeks. In the Republic of Korea, the heaps are covered with thin plastic to retain heat and prevent insect breeding. Where materials are in short supply, the alternate layers can be added as they become available. Moreover, all the materials can be mixed together in the pile provided that the proper proportions are maintained. Shredding the material speeds up decomposition considerably. Most materials can be shredded by running a rotary mower over them several times. Where sufficient nitrogenous material is not available, a green manure or leguminous crop such as sun hemp is grown on the fermenting heap by sowing seeds after the first turning. The green matter is then turned in at the time of the second mixing. The process takes about four months to complete (FAO, 2003).

**Chinese rural composting – pit method**

In this method, the composting is generally carried out in a corner of a field in a circular or rectangular pit (FAO, 1980). Rice straw, animal dung (usually pig), aquatic weeds and green

manure crops are used. Silt pumped from river beds is often mixed with the crop residues. The pits are filled layer by layer, each layer being 15 cm thick. Usually, the first layer is a green manure crop or water hyacinth, the second layer is a straw mixture **(Plate 1)** and the third layer is animal dung. These layers are alternated until the pit is full, when a top layer of mud is added. A water layer of about 4 cm deep is maintained on the surface to create anaerobic conditions, which helps to reduce N losses. The approximate quantities of the different residues in terms of tonnes per pit are: river silt 7.5, rice straw 0.15, animal dung 1.0, aquatic plants or green manure 0.75, and superphosphate 0.02. In total, there are three turnings. The first turning is given one month after filling the pit and, at this time, the superphosphate is added and mixed in thoroughly. Water is added as necessary. The second turning is done after another month and the third two weeks later. The material is allowed to decompose for three months and produces about 8 tonnes of compost per pit (FAO, 2003).

#### I.3.1.2 Rapid methods

##### I.3.1.2.1 Aerobic high temperature composting

**Chinese rural composting – high temperature method**

This form of compost is prepared mainly from night soil, urine, sewage, animal dung, and chopped plant residues at a ratio of 1:4. The materials are heaped in alternate layers starting with chopped plant stalks and followed by human and animal wastes; water is added to an optimal amount. At the time of making the heap, a number of bamboo poles are inserted for aeration purposes. Once the heap formation is complete, it is sealed with 3 cm of mud plaster. The bamboo poles are withdrawn on the second day of composting, leaving the holes to provide aeration. Within four to five days, the temperature rises to 60–70 °C and the holes are then sealed. The first turning is usually done after two weeks and the moisture is made up with water or animal or human excreta; the turned heap is again sealed with mud. The compost is ready for use within two months (FAO, 2003). In some locations, a modified method of high temperature composting is used. The raw materials, crop stalks (30 percent), night soil (30 percent) and silt (30 percent), are mixed with superphosphate at the rate of 20 kg of superphosphate per tonne of organic material (FAO, 2003). The compost heaps have aerating holes made by inserting bundles of maize stalks instead of bamboo poles.

**Ecuador on-farm composting**

Under this method, the raw materials utilized for compost making are: animal manure: from cows, pigs, poultry, horses, donkeys, ducks, etc.; crop residues and weeds: maize, bean, broad bean, groundnut, coffee and weeds; agro-industrial wastes, ash and phosphate rock; wood cuttings; topsoil from the forest or from an uncultivated or sparingly cultivated area; freshwater (FAO,2003).

The raw materials are put in layers in the following sequence (Figure 2):

- a layer of crop residues (20 cm);
- a layer of topsoil (2 cm);
- a layer of manure (5–10 cm).

Ash or phosphate rock (50 g/m2) is then spread on the surface, and freshwater is sprinkled on the material. The above steps are repeated until a height of about 1–1.2 m is reached. It is recommended to begin the heap by constructing a lattice of old branches, and to place two or three woodcuttings vertically along the lattice in order to facilitate ventilation. The heap should be 2 m × 1–1.2 m × 1–1.2 m. Once a week water should be added to the heap. However, too much water could lead to the leaching of nutrients. After three weeks, the heap must be mixed to ensure that all materials reach the centre. During the process, the temperature rises to 60–70 °C, and most weed seeds and pathogens are killed. While it may take about two to three months to prepare the compost in a warm climate, in cold regions it could take five to six months.

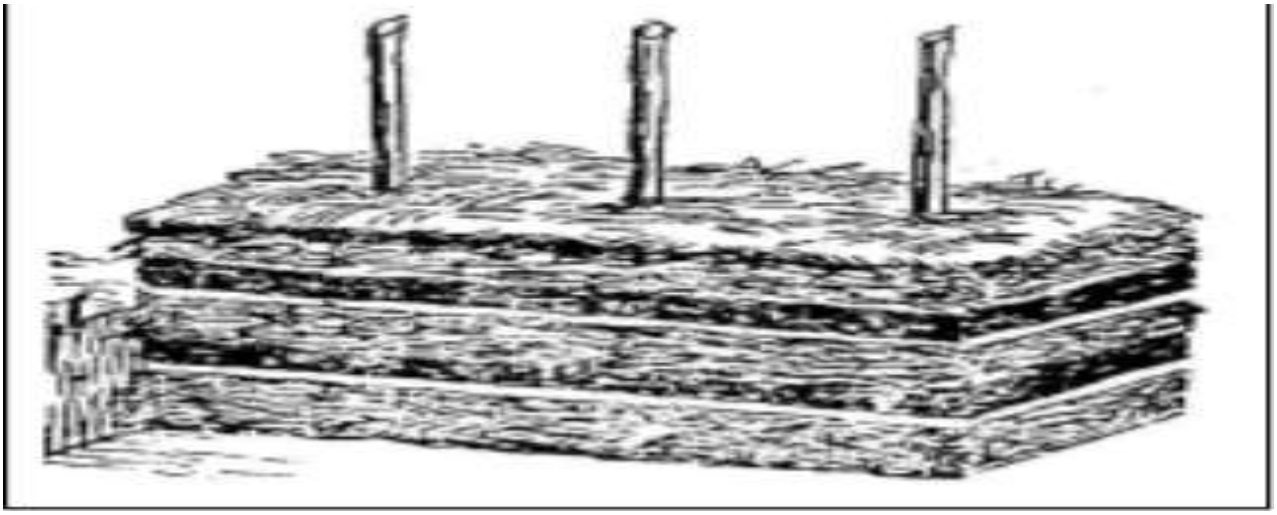


**Figure 2:** Ecuador heap composting

**Berkley rapid composting method – shredding and frequent turning**

This method (Raabe, 2001) corrects some of the problems associated with the earlier methods of composting. The process can produce compost in two to three weeks. Several factors are essential to the rapid composting method:

- Material composts best when it is 1.25–3.75 cm in size. Soft, succulent tissues do not need chopping into very small pieces because they decompose rapidly. The harder or woodier the tissues, the smaller they need to be in order to decompose rapidly. Woody material should be passed through a grinder. Chopping material with a sharp shovel is effective. When pruning plants, the material should be cut into small pieces using the pruning shears. This requires a little effort but the results are worth it
- For the composting process to work most effectively, the material to be composted should have a C:N ratio of 30:1. Mixing equal volumes of green plant material with equal volumes of naturally dry plant material yields such a ratio. The green material can be grass clippings, old flowers, green prunings, weeds, fresh garbage and fruit and vegetable wastes. The dried material can be fallen leaves, dried grass, straw and woody materials from prunings.
- Materials that should not be added to a composting pile include: soil, ashes from a stove or fireplace, and manure from carnivorous animals. Manures from herbivorous animals such as rabbits, goats, cattle, horses, elephants and fowl can be used. Once a pile has been started, nothing should be added. This is because it takes a certain length of time for the material to break down and anything added has to start at the beginning, thus lengthening the decomposition time for the whole pile. Excess material should be as dry as possible during storage until a new pile is started. Moist stored materials start to decompose. If this occurs, they will not be effective in the compost pile. Nothing needs to be added to the organic materials to make them decompose. The micro-organisms active in the decomposition process are ubiquitous where plant materials are found and develop rapidly in any compost pile.
- Composting works best where the moisture content of materials in the pile is about 50 percent. Too much moisture creates a soggy mass, and decomposition will then be slow and the pile will smell. Where the organic material is too dry, decomposition is either very slow or does not occur at all.

- Heat, which is very important in rapid composting, is supplied by the respiration of the micro-organisms as they break down the organic materials. To prevent heat loss and to build up the amount of heat necessary, a minimum volume of material is essential. Them pile should be at least 90 cm × 90 cm × 90 cm in size. Where the dimensions are less than 80 cm, the rapid process will not occur. Heat retention is better in bins than in open piles, so rapid composting is more effective where bins are used. In addition, the use of bins is much neater. High temperatures favour the micro-organisms that are the most rapid decomposers; these micro-organisms function at about 71 °C and a good pile maintains itself at about that temperature.

- The compost pile needs to be turned to prevent it from overheating. If the temperature in the pile rises much above 71 °C, the micro-organisms will be killed, the pile will cool, and the whole process will have to start again from the beginning. Turning the pile prevents overheating and aerates the pile, both necessary conditions for keeping the most active decomposers functioning. The pile should be turned in a manner that the material is moved from the outside to the centre. In this way, all the material reaches optimal temperatures at various times. Owing to heat loss around the margins, only the central portion of the pile is at the optimal temperature. Because of the need for turning, it is desirable to have two bins so that the material can be turned from one into another. Bins with removable slats in the front facilitate the turning process. Bins with covers retain the heat better than those without. Once the decomposition process starts, the pile becomes smaller and, because the bin is no longer full, some heat will be lost at the top. This can be prevented by using a piece of polyethylene plastic slightly larger than the top area of the bin. After the compost has been turned, the plastic is placed directly on the top of the compost and is tucked in around the edges. If the material in the pile is turned every day, it will take two weeks or a little longer to compost. If turned every other day, it will take about three weeks. The longer the interval between turning, the longer it will take for the composting to finish.

- If the procedure is followed properly, a pile heats to a high temperature within 24–48 hours. If it does not do so, this means that the pile is too wet or too dry or that there is not enough green material (or N) present. If too wet, the material should be spread out to dry. If too dry, moisture should be added. If neither of these, then the N is low (a high C:N ratio), and this can be corrected by adding materials high in N (such as ammonium sulphate, grass clippings, fresh chicken manure or urine diluted 1 to 5).

- Where the C:N ratio is less than 30:1, the organic matter decomposes very rapidly but there is a loss of N. This is given off as ammonia, and where this odour is present in or around acomposting pile, it means that valuable N is being lost in the air. This can be counteracted by adding sawdust to that part of the pile where there is an ammonia odour (sawdust is very high in C and low in N). Some covering for the pile may be necessary in order to keep the composting materials from becoming too wet during the rainy season.

- The rapid decomposition can be detected by a pleasant odour, by the heat produced (visible in the form of water vapour given off during the turning of the pile), by the growth of white fungi on the decomposing organic material, by a reduction of volume, and by the materials changing colour to dark brown. As composting nears completion, the temperature drops and, finally, little or no heat is produced. The compost is then ready to use. If the material was not chopped into small pieces during the preparation phase, screening the material through 2.5–cm–mesh chicken wire will hold back the large pieces. These can be added to the next pile and eventually they will decompose.

#### I.3.1.3 The on-farm composting technologies

All the composting technologies are based on three main phases: mixture preparation, bio-oxidative phase, and maturation phase. The difference between composting technologies lies mainly in the mode of running the bio-oxidative phase and so they involve different technical economic management choices (Maria Pergola *et al.,* 2017). Among the many technologies available for the bio oxidative phase, there are:

##### I.3.1.3.1 passive composting in windrow or pile

It involves the formation of the mix of raw material into a pile or windrow, periodically turned primarily to rebuild the porosity. Aeration is accomplished through the passive movement of air through the pile. So, this requires that the pile/windrow should be small enough to allow for this passive air movement (USDA, 2000). It is very cheap and recommended for small farms that do not have big space problems (Maria Pergola *et al.*, 2017).

##### I.3.1.3.2 Composting in static windrow with active aeration

This is useful mostly for the swiftness of the composting time and for the limited space required; it uses blowers to blow air into the pile using positive pressure to provide oxygen and cooling. Blowers can be run continuously or at intervals. (Maria Pergola *et al.*, 2017). This composting

technique requires a base layer made of porous material (wood chips or straw) to distribute air evenly either as it enters or leaves the aeration pipes, and a top layer (finished compost or sawdust) to absorb odours, deter flies, and retain moisture, ammonia, and heat (USDA, 2000).

#### 1.3.1.3.3 Composting in confined systems

It can be done in wooden bins, unused storage bins, or some other appropriate vessel either with or without a roof; silo or rotating tube. Such technology is not very common in the agro-industrial sector due to the high costs of the initial investment and the in itinere management, making it suitable only when dealing with large quantities of compostable material (Maria Pergola *et al.*, 2017).

### I.3.1.4 Composting process

Composting, is an environmentally acceptable method of waste treatment (Yvette B *et al*., 2000). It is an aerobic biological process which uses naturally occurring microorganisms to convert biodegradable organic matter into a humus like product. The process destroys pathogens, converts N from unstable ammonia to stable organic forms, reduces the volume of waste and improves the nature of the waste. It also makes waste easier to handle and transport and often allows for higher application rates because of the more stable, slow release, nature of the N in compost (Fauziah *et al.*, 2009). The effectiveness of the composting process is influenced by factors such as temperature, oxygen supply (aeration) and moisture content. There are two fundamental types of composting aerobic and anaerobic (Saleh *et al*., 2011):

#### Aerobic

Composting is the decomposition of organic wastes in the presence of oxygen (air); products from this process include CO2, NH3, water and heat. This can be used to treat any type of organic waste but, effective composting requires the right blend of ingredients and conditions (Saleh Ali Tweib *et al.*, 2011). These include moisture contents of around 60-70% and carbon to nitrogen ratios (C/N) of 30/1. Any significant variation inhibits the degradation process. Generally wood and paper provide a significant source of carbon while sewage sludge and food waste provide nitrogen. To ensure an adequate supply of oxygen throughout, ventilation of the waste, either forced or passive is essential. (Yvette B *et al*., 2000).

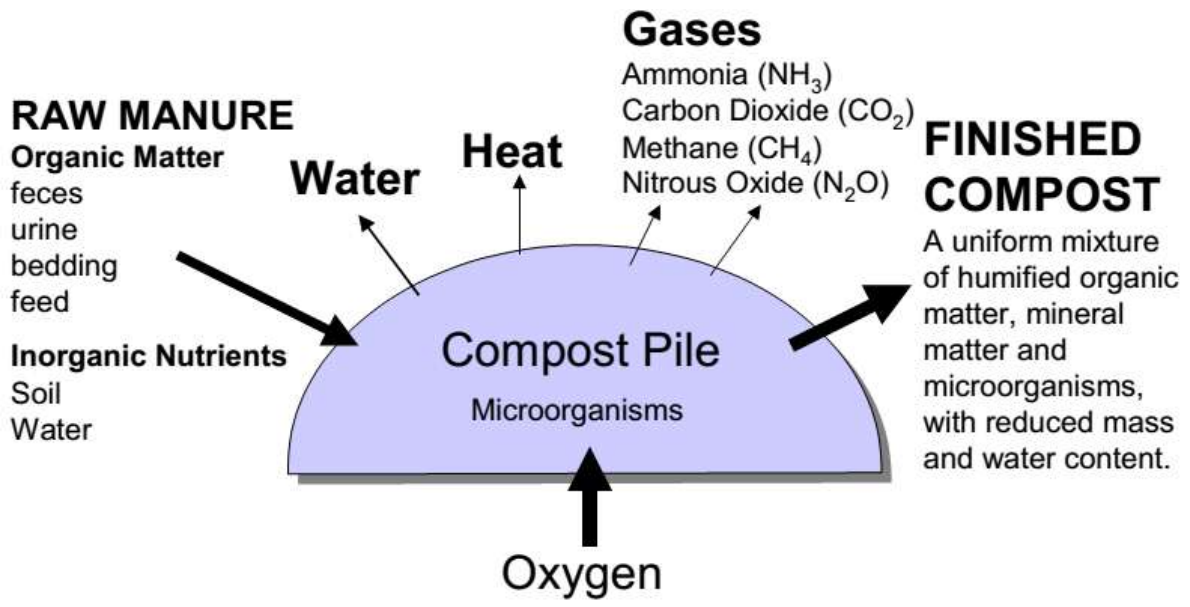



**Figure 3:** The diagram illustrating the composting process for raw manure, and inputs and outputs of the composting (Kuo *et al.*, 2014)

### I.3.1.5 Phases of composting

**Mesophilic Phase (25–40◦C)**

In this first phase, also called starting phase, energy-rich, easily degradable compounds like sugars and proteins are abundant and are degraded by fungi, actinobacteria, and bacteria, generally referred to as primary decomposers. Provided that mechanical influences (like turning) are small, also compost worms, mites, millipedes, and other mesofauna develop, which mainly act as catalysts. Depending on the composting method, the contribution of these animals is either negligible or, as in the special case of vermicomposting, considerable. It has been demonstrated that the number of mesophilic organisms in the original substrate is three orders of magnitude higher than the number of thermophilic organisms, but the activity of primary decomposers induces a temperature rise (Heribert Insam, 2007).

**Thermophilic Phase (35–65◦C)**

Organisms adapted to higher temperatures get a competitive advantage and gradually, and at the end, almost entirely replace the mesophilic flora. Previously flourishing mesophilic organisms die off and are eventually degraded by the succeeding thermophilic organisms, along with the remaining, easily degradable substrate (Heribert Insam, 2007). The decomposition continues to be fast, and accelerates until a temperature of about 62◦C is reached. Thermophilic fungi do have growth maxima between 35 and 55◦C, while higher temperature usually inhibits

fungal growth. Thermotolerant and thermophilic bacteria and actinobacteria are known to remain active also at higher temperatures. Despite the destruction of most microorganisms beyond 65◦C, the temperature may rise further and may exceed 80◦C. It is probable that this final temperature rise is not due to microbial activity, but rather is the effect of abiotic exothermic reactions in which temperature-stable enzymes of actinobacteria might be involved (Heribert Insam, 2007). The temperature range of psychrotolerant, mesophilic, and thermophilic organisms and their generation times are shown in Figure 4.

Microbiology of the composting process

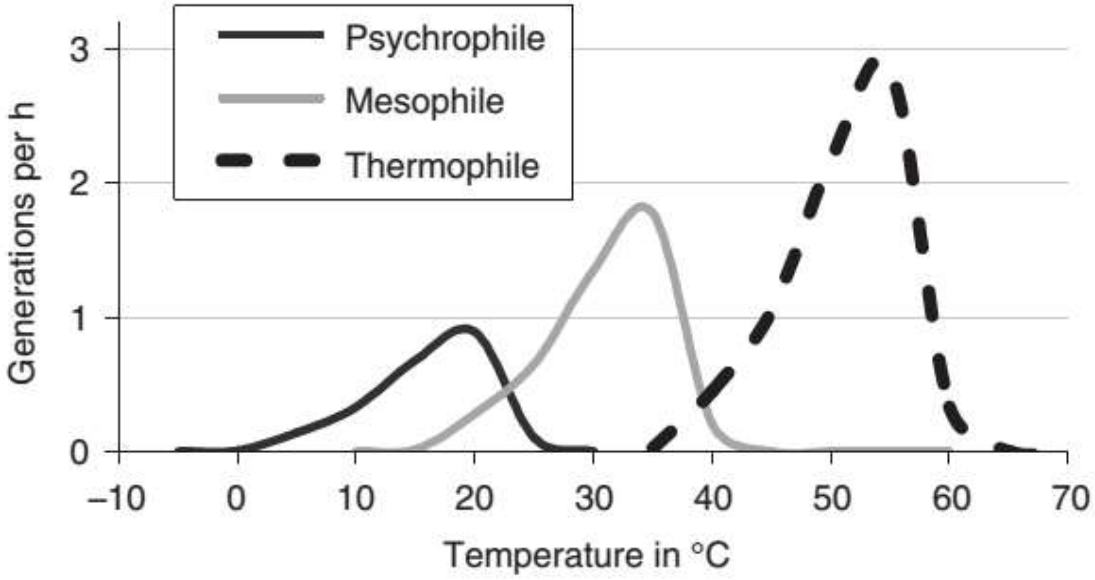



**Figure 4:** Temperature range of psychrotolerant, mesophilic, and thermophilic organisms, and their generation time.

The same temperatures are not reached in all zones of a compost pile; thus, it is important that, through regular turning, every part of the substrate is moved to the central, hottest part of the pile. From a microbiological point of view, four major zones may be identified within a pile (as shown in Figure 5). The outer zone is the coolest, and well supplied with oxygen; the inner zone is poorly supplied with oxygen; the lower zone is hot, and well supplied with oxygen; while the upper zone is the hottest zone, and usually fairly well supplied with oxygen. The thermophilic phase is important for hygienization. Human and plant pathogens are destroyed; weed seeds and insect larvae are killed. Not only the temperature during the thermophilic phase, but also the presence of a very specific flora dominated by actinobacteria, are important for hygienization through the production of antibiotics. The disadvantage of temperatures

exceeding 70◦C is that most mesophiles are killed, and thus the recovery is retarded after the temperature peak. This may, however, be avoided by appropriate measures for recolonization (Heribert Insam, 2007).

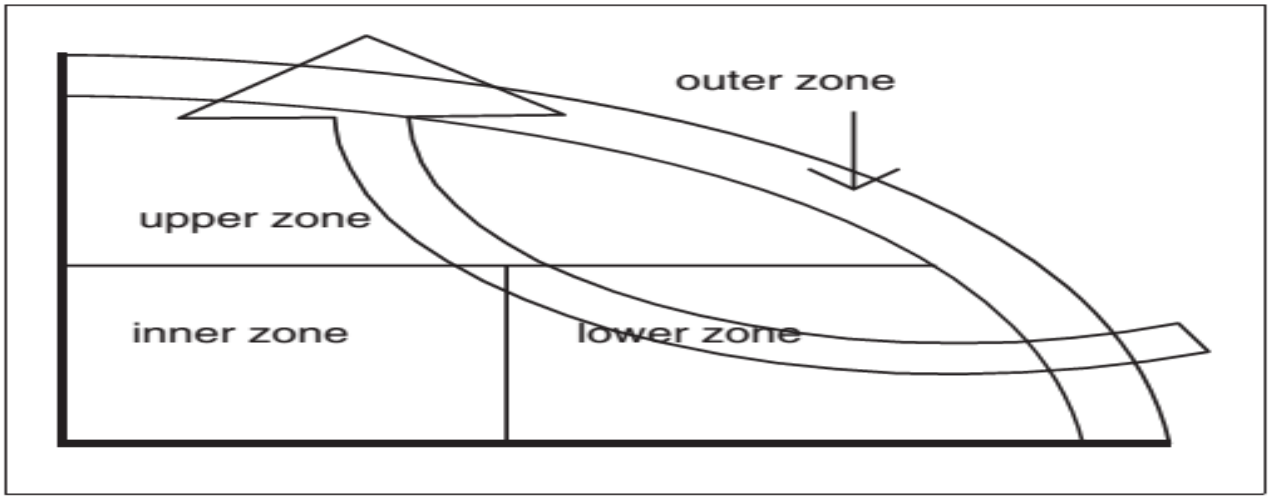



**Figure 5:** Cross section of a compost windrow (major zones and convection stream are indicated).

**Cooling Phase (Second Mesophilic Phase)**

When the activity of the thermophilic organisms ceases due to exhaustion of substrates, the temperature starts to decrease. Mesophilic organisms recolonize the substrate, either originating from surviving spores, through spread from protected microniches, or from external inoculation. While in the starting phase organisms with the ability to degrade sugars, oligosaccharides and proteins dominate, the second mesophilic phase is characterized by an increasing number of organisms that degrade starch or cellulose. Among them are both bacteria and fungi (Heribert Insam, 2007).

**Maturation Phase**

During the maturation phase, the quality of the substrate declines, and in several successive steps the composition of the microbial community is entirely altered. Usually, the proportion of fungi increases, while bacterial numbers decline. Compounds that are not further degradable, such as lignin–humus complexes, are ormed and become predominant. (Heribert Insam, 2007).

## I.3.1.6 Nitrification within composting

### I.3.1.6.1 Nitrogen cycling and nitrification within the cycle

The fifth most abundant element in our solar system is nitrogen, and it is essential for the synthesis of nucleic acids and proteins. (Rafaela *et al*., 2017). Ammonium from these and other organic compounds is returned to the environment when organisms die and its fate depends on whether the local environment contains oxygen. In the presence of oxygen, NH4 + is sequentially oxidized to $NO_3$ by specific groups of bacteria and archaea (Canfield *et al*., 2010). Thus, mineralization of N is described as a two-stage process consisting of ammonification (the release of NH4 + from organic N) and nitrification (the further oxidation of NH4 +-N to NO3), (Edwards and Daniel, 1992 ; Rafaela *et al*., 2017). Then, nitrate or ammonium can be taken up by plants to synthesize new organic- N compounds which are essential for living organisms. Additionally, nitrate can also be transformed into N2 through denitrification under anoxic conditions (Wang *et al*., 2015). In natural systems, specific organisms are in charge of returning the N2 into an available form of N for growing plants (ammonium and then, nitrate). The research on nitrification within composting is complex and has to take into account a number of aspects and variables. Nitrogen dynamics during composting has been studied by many researchers. Some authors have outlined and measured the N balance within the process (Zeng *et al.,* 2012; Janczak *et al*., 2017). Jointly with carbon, nitrogen is the main element in the composting process because it contributes to microbial development and, therefore, the development of the process itself. Nitrogen in feedstocks is present mainly in an organic form and the principal processes that can occur during composting include: ammonification, loss of NH3 by volatilization in gases or condensates, immobilization (assimilation) forming new organic N molecules, nitrification (liquid phase), leaching and denitrification (Cáceres *et al*., 2015; Meng *et al*., 2016). The processes behind N cycle within composting are presented in Figure 6.

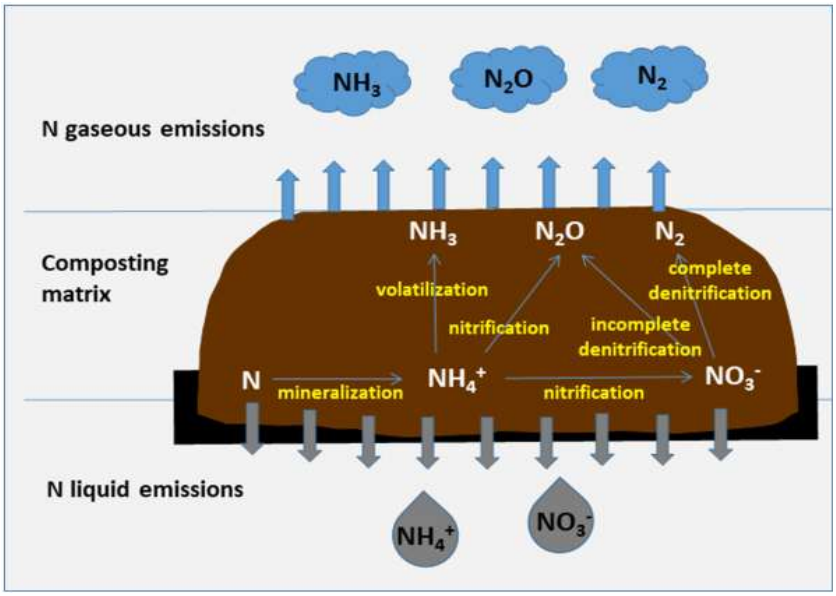



**Figure 6:** Nitrogen cycle within composting (Rafaela *et al*., 2017)

N can be found mainly, in organic waste materials, in organic forms within molecules like proteins, DNA and other key cellular compounds. During the first stages of the composting process, proteinaceous materials are broken down until releasing $NH_4^+$-N. Then, ammonification could take place during composting at the beginning, typically showing an initial increase (peak) that coincides with the maximum biodegradation period. However, some authors have also demonstrated the existence of a second peak of ammonium release during the process (Zeng *et al*., 2012; Cáceres *et al*., 2016). Ammonia is found in the liquid phase, but it is also adsorbed by the solid phase. There are materials like fresh hen manure in which the density of ammonifiers is high and the ammonification process can proceed very quickly (Mahimairaja *et al*., 1994). Under high temperature (65–70C) and pH conditions (8.4–9.0) (Chowdhury *et al*., 2014), the $NH_3$-N form is volatilized very easily to the gas form and lost. However, $NH_4^+$-N could also be transformed into a more soluble mineral form (i.e. nitrates) through nitrification and reduce the NH3 emissions (Zeng *et al*., 2013). In this way, ammonium release and nitrate formation during composting can be regarded as concatenated processes. However, it is also known that the $NH_4^+$/NH3 transformation is bilateral, since part of $NH_3$ can be immobilized in turn by biomass to synthesize organic N (Norg) (Zeng *et al*., 2012; Meng *et al*., 2016). Some authors have stated that nitrogen assimilation could take place in the first months of composting process (Zeng *et al*., 2012), but it can also be carried out during the curing phase. Once nitrates are produced, this nitrogen form can be lost through denitrification under anoxic conditions (Wang *et al*., 2015). Other authors have suggested that during sewage

sludge composting, the nitrogen transformation reactions could occur simultaneously, including ammonification, $NH_3$ assimilation, nitrification and denitrification (Meng *et al*., 2017). However, the predominant reaction would alternate according to the substrate and environmental conditions during composting.

During the process, N can be lost through volatilization as $NH_3$, nitrogen oxides (NOx), nitrous oxide ($N_2O$) or dinitrogen ($N_2$) (Nigussie *et al*., 2016). On average, the total loss of N, which occurs mostly in the thermophilic phase, is estimated at 40–70% of the initial N content (Nigussie *et al*., 2016).

### I.3.1.6.2 Mechanisms behind nitrification

Nitrification is a two-step sequencing biological oxidation process of $NH_4^+$ to $NO_2$ and $NO_3$ (1) intermediated by several microbial communities (Sims and Wolf, 1994; Angnes *et al.*, 2013; Ge *et al*., 2015).

$$NH^+_4 \xrightarrow[O_2]{} NO^-_2 \xrightarrow[O_2]{} NO^-_3 \quad (1)$$

The conversion of $NH_4^+$ to $NO_2$ comprises two steps with hydroxylamine ($NH_2OH$) as the intermediate product (Ge *et al*., 2015). In the first step, $NH_3$, rather than $NH_4^+$, which is the actual substrate (Suzuki *et al*., 1974), is oxidized to $NH_2OH$ via catalysis by ammonia monooxygenase (AMO). In the second step, $NH_2OH$ is further oxidized to $NO_2$ via catalysis by hydroxylamine oxidoreductase (HAO). The first step in nitrification generates a proton that could acidify the medium (Ge *et al.*, 2015). Part of the $NH_4^+$ is used for cell growth as N source, while carbon dioxide serves as carbon source. The process is carried out by nitrifying bacteria that are autotrophic organisms that consume alkalinity (bicarbonates) as a source of Carbon. Alkalinity needs are, approximately, of 7.1 mg $CaCO_3.mg^{-1}$ $NH_3$ for both cell synthesis and nitrification (Cáceres *et al*., 2015).

### I.3.1.7 The microorganisms Involved

#### I.3.1.7.1 Bacteria

The importance of non-mycelial bacteria during the composting process was long neglected, probably because of the better visibility of fungi and actinobacteria. In some composting processes, e.g., the composting of sewage sludge, bacteria are more important than fungi from the beginning. If temperatures are kept under 60 ˚C, more than 40% of the solids are degraded within the first 7 days, almost entirely through bacterial activity (Strom, 1985). The temperature range from 50 to 65◦C is of selective advantage for bacteria, and in particular for the genus

Bacillus. When temperatures exceeded 65◦C, B. stearothermophilus often is dominant, almost like in a pure culture. Most probably, obligate anaerobic bacteria are also common in composts, but so far, very little information is available. During the preparation of agaricus substrates, Eicker (1981) found evidence for sulfate reduction under thermophilic conditions ( Heribert Insam, 2007).

#### I.3.1.7.2 Actinobacteria

Actinobacteria prefer neutral or slightly alkaline pH and are able to degrade relatively complex substrates. Several are thermotolerant, or even thermophilic, with a temperature range from 50 to 60◦C. Most actinobacteria grow best when the substrate is moist and the oxygen supply is good. These conditions are usually given when the most easily degradable substrates have already been consumed by bacteria, and when the temperatures rise beyond 45◦C. Actinobacteria are, however, also well represented in the later consortia ( Heribert Insam, 2007).

A special case is the composting of cultivation substrate for Basidiomycetes. In this special case, actinobacterial growth is especially strong during the second phase. Actinobacteria are visible by the naked eye in thick mats, and this phase is called the "firefang" period (temperature around 45◦C, relatively low moisture). For the cultivation of Agaricus, this actinobacterial phase is decisive for the success. It is attempted to maintain a temperature of 48◦C throughout the entire substrate (and not only within a certain zone) by regulating humidity and air supply. The main purpose is microbial re-assimilation of ammonium. Overheating of the compost (>70◦C) would lead to an irreversible alteration of the material, and ammonia would be released (Heribert Insam, 2007).

#### I.3.1.7.3 Thermus and deinococcus group

Members of the Thermus/Deinococcus group grow on organic substrates at temperatures from 40 to 80◦C, with optimum growth between 65 and 75◦C. The numbers in biowaste composts were as high as 107–1010 g−1 dry weight of compost (Beffa *et al*., 1996). Thus, it seems that Thermus species, previously known only from geothermal sites, have probably adapted to the hot-compost system and play a major role in the peakheating phase. Also, a number of autotrophic bacteria were isolated from composts. These non-sporing bacteria grew at 60–80◦C, with optima of 70–75◦C, and closely resembled Hydrogenobacter strains that previously were known only from geothermal sites. They obtain their energy by oxidizing sulfur or hydrogen, and synthesize their organic matter from CO2 (Beffa *et al*., 1996 and Heribert Insam, 2007).

#### I.3.1.7.4 Archaea

Many archaea are known to be thermophilic or even hyperthermophilic. They have primarily been isolated from hypothermal vents. Only in a few cases, archaea have been isolated from composts (Stackebrandt *et al*., 1997), but since considerable methanogenesis in compost piles has recently been reported (Cabanas-Vargas and Stentiford, 2006), it is likely that methanogenic archaea may be found if specifically searched for. The reason for the relatively low abundance of archaea probably is that they are usually oligotrophic, and their generation times are much higher than those of bacteria, which make them unsuited to rapidly changing conditions (Heribert Insam, 2007).

#### I.3.1.7.5 Fungi

During the starting phase, fungi compete with bacteria for the easily available substrates. Since the maximum specific growth rates of bacteria exceed that of fungi by one order of magnitude (Griffin, 1985), fungi are very soon out-competed. Also, a good supply of oxygen is more important for fungi than for bacteria, and even in force-aerated systems, temporary anoxic conditions may occur. (Heribert Insam, 2007). For these reasons, but also because of the lower thermotolerance, fungi play a negligible role during the thermophilic phase. One exception is the composting of substrates that are particularly rich in cellulose and in lignin. In that case, fungi remain most important throughout the entire process. In the later phases of composting, the water potential decreases, which is an advantage for fungi (Heribert Insam, 2007).

### I.3.1.8 Factors affecting the composting process

#### I.3.1.8.1 Substrates

During the process of composting , the substrate is the waste to be composted; and similar to any other biological process, the chemical and physical characteristics of the substrate are critical in the viability of the process (in terms of course and rate). Essentially, it is the availability of the nutrients to the microorganisms and the concentration and balance of the nutrients that dictate the feasibility of the composting process. Some of the most important physical characteristics of the substrate are primarily related to particle size and moisture content of the material. Some of the pertinent chemical characteristics include those associated with molecular size, complexity and nature, as well as elemental makeup of the molecules (Diaz and Savage, 2007).

The complexity and nature of the molecular structure of the substrate are particularly important because these characteristics define the assimilability of the nutrients by the various microorganisms. The capacity of a microorganism to assimilate a particular substrate is a function of the microorganism's ability to synthesize the enzymes responsible for breaking down complex compounds (Diaz and Savage, 2007). The complex compounds are broken down into intermediate compounds or into an element that can be utilized by the microorganism in its metabolism and synthesis of new cellular material. In the event that all of the microbes do not have the necessary enzymes, the substrate basically remains in its original form. Therefore, the discussion on nutrients that follows should be interpreted in that light (L.F. Diaz and G.M. Savage, 2007). The waste should contain all necessary nutrients. Only rarely must or should chemical nutrients be added.

#### I.3.1.8.2 Types and Sources of Nutrients

The macronutrients for microbes are carbon (C), nitrogen (N), phosphorous (P), and potassium (K). Among the micronutrients are cobalt (Co), manganese (Mn), magnesium (Mg), copper (Cu), and a number of other elements. Calcium (Ca) falls somewhere between the macro and the micronutrients. However, the principal role of Ca probably is as a buffer, i.e., to resist change in pH level (Diaz and Savage, 2007). Even though nutrients may be present in sufficiently large concentrations in a substrate, they are unavailable to the microbes unless they are in a form that can be assimilated by the microbes and thereby become available to them. (The situation is analogous to that of cellulose in human nutrition, in that, the carbon in cellulose is of no nutritional value to a person who might chance to ingest a cellulosic material, such as paper.) An important point to remember is that availability is a function of the enzymatic makeup of the individual microbe (Diaz and Savage, 2007). Thus, certain groups of microbes have an enzymatic complex that permits them to attack, degrade, and utilize the organic matter as found in a freshly generated waste; whereas, others can utilize only the decomposition products (intermediates) as a source of nutrients. The significance of this fact is that the decomposition and, hence, the composting of a waste is the result of the activities of a dynamic succession of different groups of microorganisms in which one group, so to speak, prepares the way for its successor group (Diaz and Savage, 2007).

Another important aspect of nutrient availability in composting is that certain organic molecules are very resistant, i.e., refractory to microbial attack, even to microbes that possess the required enzymatic complex (L.F. Diaz and G.M. Savage, 2007). The consequence is that such materials

are broken down slowly, even with all other environmental conditions maintained at an optimum level. As discussed in a previous chapter, common examples of such materials are lignin (wood) and chitin (feathers, shellfish, exoskeletons). Cellulose-C is unavailable to the majority of the microbes, although it is readily available to certain fungi. Nitrogen is easily available when in the proteinaceous, peptide, or amino acid form; whereas the minute amounts present in chitin and lignin are difficultly available. Sugars and starches are readily decomposed, and fats are somewhat less so (Diaz and Savage, 2007).

#### I.3.1.8.3 C/N ratio

One of the most important aspects of the total nutrient balance is the ratio of organic carbon to total nitrogen (C/N). A C/N in the starting material of about 25–30 is optimum for most types of wastes. Living microorganisms in their metabolism utilize about 30 parts of carbon for each part of nitrogen. About 20 parts of carbon are oxidized to $CO_2$ (ATP), and 10 parts are utilized to synthesize protoplasm. Indeed, the average C/N in many bacteria is about 9–10 ( Diaz and Savage, 2007). If the amount of carbon over that of nitrogen is too great (high C/N), biological activity diminishes. In a composting operation, the manifestation could require an excessively long time to reduce the C/N to a more suitable level (Golueke, 1977). The optimum C/N is, to some extent, a function of the nature of the wastes, especially of the carbonaceous components (Diaz and Savage, 2007). If the carbon is bound in compounds broken down with difficulty by biological attack, its carbon accordingly would only become slowly available to the microbes. Compounds of this sort are chiefly lignin, some aromatics, and some physical forms of cellulose.

The only observable penalty for having a C/N lower than 20 is the loss of nitrogen through ammonia volatilization. This process is enhanced by high temperatures and basic pH (about 8–9). This loss occurs at the starting of the process during the thermophilic phase, in particular, when the material is turned in a windrow or tumbled in a reactor. Generally, the outer layer of material of an undisturbed windrow prevents the ammonia from escaping from the pile. Loss of ammonia, besides producing odors and polluting the atmosphere, reduces the nitrogen content of the final product, also limiting the value of the organic fertilizer produced (Diaz and Savage, 2007).

In a well-conducted process, the C/N decreases constantly. This is due to the biological mineralization of carbon compounds and loss as $CO_2$. If a compost has a high C/N and decomposes rapidly in the soil, it can rob the soil of the nitrogen needed to support plant growth.

If the compost has too low a C/N, the ammonia released can be phytotoxic to plant roots (Zucconi *et al*., 1981). With respect to the nutritional needs of the microbes active in composting, the C/N of the waste to be composted is the most important factor that requires attention (Diaz and Savage, 2007). Experience shows that, almost without exception, all other nutrients are present in typical organic waste in adequate amounts and ratios. Requirements with respect to the C/N are functions of the relative differences in amounts of the two elements used by the microbes in metabolism to obtain energy and in the synthesis of new cellular material. A large percentage of the carbon is oxidized to carbon dioxide by the microbes in their metabolic activities (Diaz and Savage, 2007). The remaining carbon is converted into cell wall or membrane, protoplasm, and storage products. The major consumption of nitrogen is in the synthesis of protoplasm. Consequently, much more carbon than nitrogen is required. Departures from a C/N of 25/1 to 30/1 lead to a slowing of decomposition and hence of composting. On the other hand, chances are good that nitrogen will be lost as ammonia-N if the C/N is lower than those levels (L.F. Diaz and G.M. Savage, 2007). The reason for the loss is that nitrogen in excess of the microbial needs is converted by the organisms into ammonia. A combination of high pH level and elevated temperature very likely leads to volatilization of the ammonia. If the C/N of a waste is too high, it can be lowered by adding a nitrogenous waste. Conversely, if the C/N is too low, a carbonaceous waste can be added (Diaz and Savage, 2007).

#### I.3.1.8.4 Environmental Factors

##### I.3.1.8.4.1 Temperature

Composting is a bio-oxidative microbial degradation process of mixed organic matter. This exothermic process produces a relatively large quantity of energy. Only 40–50% of this energy can be utilized by microorganisms to synthesize ATP; the remaining energy is lost as heat in the mass. This large amount of heat causes an increase of temperature in the mass and can reach temperatures of the order of 70–90◦C (Diaz and Savage, 2007). Finstein calls this process "microbial suicide" (Finstein *et al*., 1980). Indeed, high temperatures inhibit microbial growth, slowing the biodegradation of organic matter. Only few species of thermophilic bacteria show metabolic activity above 70◦C. To have a high rate of biodegradation and a maximum microbial diversity, the temperature must range between 30 and 45◦C (de Bertoldi *et al*., 1983; Finstein *et al*., 1983; Stentiford, 1993). During the composting process, in order to minimize the retention time, a feedback temperature control can be operated with a set point between 30 and 45◦C (Diaz and Savage, 2007).

However, in a composting process, the thermophilic phase should not be totally eliminated because it is the most important phase in reducing pathogenic agents. Furthermore, the thermophilic phase must be maintained at the starting of the process, when the availability of readily degradable molecules allows temperatures to reach 70◦C. In forced-aeration systems, the dominant heat-removal mechanism is evaporative cooling (vaporization of water), which accounts for perhaps 80–90% of the heat removal. In such systems, the contribution of conduction to heat removal may be small (Finstein *et al*., 1999).

**I.3.1.8.4.2 pH**

Generally, organic matter with a wide range of pH (from 3 to 11) can be composted (de Bertoldi *et al*., 1985). However, the optimum range is between 5.5 and 8.0. Whereas bacteria prefer a nearly neutral pH, fungi develop better in a fairly acidic environment. In practice, the pH level in a composting mass cannot be changed easily (Diaz and Savage, 2007).Generally, the pH begins to drop at the beginning of the process (i.e., down to 5.0) as a consequence of the activity of acid-forming bacteria that break down complex carbonaceous material to organic acids as intermediate products. When this acidification phase is over and the intermediate metabolites are completely mineralized, the pH tends to increase and at the end of the process is around 8.0–8.5 (Diaz and Savage, 2007).

High pH values in the starting material in association with high temperatures can cause a loss of nitrogen through the volatilization of ammonia. Whereas in anaerobic digestion, the critical pH level generally covers a fairly narrow range (6.5–7.5), the range in composting is so broad that difficulties due to an excessively high or low pH level are rarely encountered. Because it is unlikely that the pH will drop to inhibitory levels, there is no need to buffer the composting mass by adding lime (calcium hydroxide). Indeed, the addition of lime should be avoided because it can lead to a loss in ammonium nitrogen in the later stages of composting that exceeds the normal loss (Diaz and Savage, 2007).An exception could be in the composting of fruit wastes. With such wastes, the pH can drop to 4.5. There is some evidence that under such circumstances, the composting process can be accelerated (National Canners Association Research Foundation, 1964). At the relatively elevated temperatures and Ph levels that occur as composting progresses, the ammonium ion is volatilized and the resulting ammonia gas is lost during the aeration of the composting mass. Although some loss of ammonia almost always occurs in aerobic composting, the loss is aggravated by the presence of lime. However, the lime

does improve the physical condition of the composting wastes, perhaps partly by serving as a moisture absorbent (Diaz and Savage, 2007).

#### I.3.1.8.4.3 Oxygen availability

In general, composting is defined as aerobic process which means that the main reactions and microbial activity take place with high oxygen content. The O2 concentration in the atmospheric air is about 21% and a minimum percentage of 5–10% O2 is needed in the surrounding atmosphere of the particles. However, the air voids of the composting matrix can also be filled in with water. This happens when the feedstock shows high moisture content (about 70%) (e.g. sewage sludge, digestates, solid fraction) and high bulk density. During the first stage of composting the oxygen requirements are substantial due to the availability of fresh materials and the activity of microorganisms. At the same time, with the moisture of about 60% or more, the physical structure of the composting matrix impedes the air exchange needed to replace the CO2 produced during the process by fresh air with high O2 concentration. Therefore, the use of forced aeration can alleviate, to a certain extent, this problem (Kits *et al.*, 2017).

### I.3.1.8.5 Aeration

In composting, one of the main factors that can be most influenced by technology and around which system designs are developed is the provision of oxygen to the composting mass. The air contained in the interspaces of the composting mass, during the microbial oxidative activity, varies in composition. The carbon dioxide content gradually increases and the oxygen level falls. The average $CO_2$ plus $O_2$ content inside the mass is about 20%. Oxygen concentration varies from 15 to 20% and carbon dioxide from 0.5 to 5% (MacGregor *et al*., 1981). When the oxygen level falls below this range, anaerobic microorganisms begin to exceed aerobic ones. Fermentation and anaerobic respiration processes take over. It is, therefore, important that microorganisms have a constant supply of oxygen to maintain their metabolic activities unaltered. After a few hours of composting, the oxygen level drops to very low levels and oxygen has to be supplied by ventilation. Periodic pile turning, every one or two days, without any ventilation of the mass, cannot guarantee a constant level of oxygen inside the mass (Diaz and Savage, 2007).

Normally, oxygen is made available to the mass through ventilation (positive or negative pressure or both systems in conjunction). Ventilation, besides providing oxygen to the mass, serves other functions such as temperature and moisture control. In a composting pile at 60◦C,

the amount of air needed to control temperature and to replenish the $O_2$ consumed is in the ratio of 9:1 (air function ratio). At lower temperatures, this ratio increases (Finstein *et al*., 1986, 1987, 1999; Finstein and Hogan, 1993). The ventilation process should, therefore, be managed to supply sufficient oxygen for aerobic respiration (which, in turn, promotes heat generation) while performing associated heat removal. A satisfactory solution is to ventilate the mass at a specific rate such that de-oxygenation is avoided (Diaz and Savage, 2007). A suggested first approximation is 0.15 m3 air per wet metric ton of mass per minute.

#### I.3.1.8.6 Moisture Content

Water is essential for all microbial activity and should be present in appropriate amounts throughout the composting cycle. Optimal moisture content in the starting material varies and essentially depends on the physical state and size of the particles and on the composting system used. Normally, 60% moisture content in the starting material should be satisfactory. Because different materials have different water-holding capacities, an exact generalization cannot be made about optimal starting or time-course moisture levels (Diaz and Savage, 2007).

Too little moisture means early dehydration of the mass, which arrests the biological process giving physically stable but biologically unstable compost. Excessive water tends to plug pores and impedes gas exchange. However, a proper balance between the needs for available water and gas exchange should be maintained. Excessive moisture in the starting material could favor anaerobic processes, resulting in a slower process and low quality final product (Diaz and Savage, 2007).

In modern composting systems, it is possible to add water during the process. In a plant designed and operated for high rates of heat generation, evaporative cooling removes large amounts of water vapor. This dries the material; hence, periodic water addition may be needed to sustain high levels of microbial activity. This will be only possible in conjunction with mechanical turning (Diaz and Savage, 2007).Moisture content, however, does not lend itself to continuous or even frequent adjustment, because water addition during the process may affect a multitude of other factors. At the end of the composting process, the water content should be quite low (about 30%) in order to prevent any further biological activity in the stabilized material (Diaz and Savage, 2007).

As stated earlier, permissible moisture content and oxygen availability are closely interrelated. The basis of the close relationship is in the method of carrying out the compost process. All

methods involve the processing of the waste, largely in the same state in which it is delivered to the compost site (Diaz and Savage, 2007). In that state, it has a moisture content that is about the same as it had at the time it was generated. As such, the oxygen supply to the microbes involved is both the ambient air and the air trapped within the interstices (voids between the particles) of waste. Inasmuch as the rate of diffusion of ambient air into the mass is inadequate, the interstitial air must be the major source of oxygen. Consequently, if the moisture content of the mass is so high as to displace most of the air from the interstices, anaerobic conditions (anaerobiosis) develop within the mass. (Diaz and Savage, 2007).Therefore, the maximum permissible moisture content is the one above that the amount of air remaining within the interstices is not sufficient to assure an adequate supply of oxygen, (oxygen becomes limiting). The term "permissible" implies a level at which no nuisance will develop and at which the process will proceed satisfactorily.

The maximum permissible moisture content is a function of the structural strength of the particles that make up the material to be composted. It refers to the degree of the resistance of individual particles to compression. The compression refers only to that imposed upon particles by the weight of the mass above them. Obviously, the greater the structural strength, the higher is the permissible moisture content (Diaz and Savage, 2007). Examples of such materials are woodchips, straw, hay (dried grass), rice hulls, and corn stover. Permissible moisture contents for mixtures in which such materials predominate are as high as 75–80%. If the particles are structurally weak, they are deformed when subjected to compression, and the collective volume of the interstices is correspondingly reduced. The result is a lessening of the space available for air and water, and the permissible moisture content accordingly is lowered

Paper is the principal example of such a material (Diaz and Savage, 2007). Upon becoming wet, paper collapses and forms mats. Mixtures in which paper is the major material have an upper permissible moisture content of only 55–60%. Finally, as a mass, the material to be composted may have little or no structural strength. For the sake of convenience, such wastes are referred to as being amorphous. Common examples are fruit wastes, cannery wastes, sludges, and animal manures devoid of bedding material. To compost those materials, it is necessary to add a "bulking" agent (Diaz and Savage, 2007).A bulking agent is one that maintains its structural integrity when mixed with amorphous wastes. It may also have the capacity to absorb some moisture. Any material having a high degree of structural strength can serve as a bulking agent. In the absence of a bulking agent, an amorphous material can be subjected to a treatment such that it acquires a structural strength that is adequate for

composting. For example, upon being dried, chicken manure takes on granular texture. Unless excessively wettened, the granular particles retain their integrity when mixed with fresh manure (Diaz and Savage, 2007). In practice, some of the finished compost product is set aside for use as a bulking agent for the incoming waste. An important point to keep in mind when using a dried or composted amorphous material as a bulking agent is that the combined moisture content of it and fresh waste should not exceed 60% (Diaz and Savage, 2007).

The critical role of moisture content is not confined to windrow composting; it also applies to mechanized composting, including that in which the material is continuously agitated. As the moisture content of almost any mass is increased (i.e., up to the point at which it becomes a slurry), it takes on a tendency to mat, to clump, or to form balls, or to do all three. By coincidence, the moisture content at which problems begin to be encountered is comparable to the upper permissible moisture contents for windrowed material (L.F. Diaz and G.M. Savage, 2007). In a discussion on moisture content, the lower levels at which moisture becomes limiting should receive attention. All microbial activity ceases when the moisture content is less than 8–12%. Consequently, moisture becomes increasingly limiting as it approaches that level. In practice, it is good to maintain the moisture content at a level above 40% ( Diaz and Savage, 2007).

**I.3.1.8.7 Aesthetic Changes**

If the process is progressing satisfactorily, the composting mass loses the appearance it had as a raw waste and gradually assumes a darker hue. By the time the process is finished, it has become dark gray to brown in color. Change in odor is another eminently perceptible sequence. Within a few days, the odor of the raw waste is replaced by a collection of odors that, depending upon how well the process is advancing, range from a faint cooking odor to one redolent of putrefying flesh ( Diaz and Savage, 2007). The odors during this stage may be interlaced with the pungent smell of ammonia. If the C/N of the waste is low and the pH of the composting mass is above 7.5, the concentration of ammonia may mask other odors. Eventually, all objectionable and unobjectionable odors either disappear or are replaced by one that is suggestive of freshly turned loam. With respect to texture, the particle size tends to become smaller as a result of decomposition, abrasion, and maceration. Fibers tend to become brittle, and amorphous material becomes somewhat granular (Diaz and Savage, 2007).

### I.3.1.8.8 Molecular Changes

A change not directly perceptible to the senses is the change in molecular structure. The change is manifested by a decline in concentration of organic matter and an increase in stability (Diaz and Savage, 2007). (Organic matter often is referred to as "volatile matter" because combustion converts its carbon into carbon dioxide.) Because the compost process is a biological decomposition, oxidation of the carbon in organic solids to carbon dioxide is an important activity (Diaz and Savage, 2007).Consequently; a portion of the organic matter is converted to carbon dioxide. The controlled decomposition feature of composting makes it a degradative process in that complex substances are reduced to simpler forms. Complex molecules that are subject to biological decomposition (i.e., are biodegradable) are converted into simpler forms. Molecules that either are only partly or are completely unbiodegradable (i.e., refractory) tend to remain unchanged. The trend then, is toward increased stability inasmuch as a part of the decomposable mass is lost or reduced to simple forms and the refractory materials remain unchanged (Diaz and Savage, 2007).

A trend has developed during the past decade to divide the compost process into two stages, namely, the "compost" ("active") stage and the "maturation" ("ripening," "curing") stage. The term "compost stage" applies to the period of rapid rise in temperature and may include the early plateau period (Diaz and Savage, 2007).The term "maturation stage" includes the greater part of the plateau period and extends to and beyond the period of temperature decline. The division is strictly arbitrary in that composting takes place throughout the process, i.e., it is not discontinuous. The division appeals to entrepreneurs for specific systems. With it, they can speak of "composting" as being done in terms of 2- or 3-day detention periods through the use of their particular systems (Diaz and Savage, 2007). The accompanying 30- to 90-day maturation requirement is mentioned only in passing. Claims of 1- to 3-day composting are misleading.

### I.3.1.9 Indicators for monitoring the performance of a compost system.

A close review of the course of the compost process reveals four particular features that can serve as useful indicators for monitoring the performance of a compost system. They are: (1) temperature rise and fall; (2) change in odor and appearance; (3) change in texture; and (4) destruction of volatile solids (i.e., organic matter) ( Diaz and Savage, 2007). The magnitude or intensity of the four features is much reduced if the wastes have a heavy concentration of inert material. Tertiary sludge is a good example. Upon being exposed to the appropriate operating

and environmental conditions, failure of the temperature of the feedstock to begin to rise rapidly within 1–3 or 4 days indicates that something is drastically amiss. A highly probable cause is too much or too little moisture. If malodors seem to be developing, then the problem is due to too much moisture (Diaz and Savage, 2007). No odor is detected if the material is too dry. Another possible cause is an excessively high C/N. However, even with a high C/N, some increase in temperature should be detected. A pH at an inhibitory level could be a cause. Excessive moisture can be alleviated through the introduction of bulking material or by increasing the rate of aeration. Aeration removes

Factors that affect the process 61 moisture by way of evaporation. Obviously, a moisture shortage is eliminated through the addition of water. The addition of a highly nitrogenous waste (sewage sludge, and poultry, pig, or sheep manure) is the solution for a high C/N. A low pH can be raised through the addition of lime, keeping in mind the guidance recommended in the section on hydrogen ion level (Diaz and Savage, 2007).

After the compost process has begun its course, a sharp deviation in any of the parameters mentioned in the preceding paragraphs indicates trouble. Thus, a sudden sharp dip in temperature during the period that normally would be a time of exponential rise is an indication of the existence of some potentially serious problem. In a windrow, the dip generally is due to an excess of moisture. In a mechanical system, it might be malfunctioning of the aeration equipment (Diaz and Savage, 2007). If excessive moisture is the cause, increased aeration (turning) is the best remedy for a windrow system. A more gradual but persistent decline during what should be the period of exponential rise or the “plateau” period is a sign either of inadequate aeration or of insufficient moisture.

The occurrence of objectionable odors invariably is a symptom of anaerobiosis caused by an excessively high moisture content or by inadequate aeration. Inasmuch as the causative factor is anaerobiosis, the corrective measure is to increase the supply of oxygen. Consequently, the olfactory sense may be regarded as being an excellent device for monitoring adequacy of aeration. With a mechanized system, the olfactory sense can be supplemented by mechanical devices designed to monitor the oxygen concentration in the incoming and outgoing air streams. Basically, it should be possible to find some oxygen in the outgoing air stream (Diaz and Savage, 2007). The presence of oxygen in the air discharged from a composting pile does not by itself imply adequate aeration. Aeration must be accompanied by proper air distribution throughout the pile.

### 1.3.1.10 Determination of degree of stability

As previously indicated, it is not simple to determine the stability and maturity of a sample of compost visually or by means of a single analytical parameter. The attainment of a dark color or an earthy odor is not an indication, because these characteristics may be acquired long before stability is reached. Reaching a C/N lower than 20/1 also is not indicative. For example, the C/N of raw manures may be lower than 20/1 ( Diaz and Savage, 2007). Dryness should not be confused with stability either. It is true that if the moisture content is lower than 15–20%, microbial activity is minimal, and the product may seem to have the external attributes of stability. The actual situation, however, is that as soon as the moisture content of the material is increased, the material assumes the degree of stability it had prior to dehydration. Although the fallacy of equating stability with dehydration may seem obvious, it nevertheless has been seriously offered as evidence by certain entrepreneurs (Diaz and Savage, 2007). The onset of a persistent decline in temperature, despite the continued presence of optimum conditions (i.e., no factor is limiting), indicates that the process is coming to an end and the composting mass is approaching stability. From past observations, it may be safely assumed that about the time the temperature begins to approach ambient temperature; the composting mass is sufficiently stable for storage and for use.

### I.3.1.11 Plant pathogen destruction during composting

During Composting Several mechanisms of pathogen inactivation are possible within compost systems, including thermal inactivation, microbial antagonism and/or competition for nutrients, toxicity from by-products of organic matter decomposition (e.g. ammonia, sulfides, organic acids, and phenolic compounds), and enzymatic breakdown (Ryckeboer 2002; Elorrieta *et al.*, 2003; Noble and Roberts 2003; Guan *et al*., 2004; Idelmann and Pickering 2006). It is generally accepted that the elevated temperatures that occur during composting are the most important and most universal contributor to pathogen inactivation (Ryckeboer 2002; Noble and Roberts 2003; Idelmann and Pickering 2006, Kristine M. Wichuk *et al*., 2013). Temperature/heating is also the only means of pathogen eradication that can be easily monitored and regulated/controlled during composting (Tee *et al*., 1999; Idelmann and Pickering 2006). For this reason, time-temperature conditions are generally specified in compost guidelines and as a means of controlling pathogenic organisms.

### I.3.1.12 Overview of plant pathogen eradication during composting

Different types of plant pathogens respond differently to composting; some are rapidly eradicated even at relatively low temperatures, while others require high temperatures and long exposure times. The majority of plant pathogens appear to be sensitive to conditions existing in compost heaps (elevated temperature and other factors), and composting at thermophilic temperatures consistently reduces phytopathogen levels in composted materials. The effectiveness of composting in completely eradicating plant pathogens, however, is dependent on the type of organism and particular species of concern. Based on reported results, it appears that the most heat-sensitive groups of phytopathogens are bacteria and nematodes; the vast majority of pathogens from these two groups are easily eliminated during composting, provided that elevated temperatures are attained. Many fungi and some viruses are also unable to survive high-temperature composting, though certain species, such as TMV, F. oxysporum, and P. brassicae, are heat tolerant. It is somewhat difficult to specify an ideal compost time-temperature limit (or range) which will be effective in eliminating most phytopathogens, because of the variation between species and the impreciseness of evaluating these conditions in actual composting systems (Kristine Wichuk *et al*., 2013).

In many of the small- and full-scale composting studies done, reported time-temperature conditions are based on widely spaced data collection (in time and location). Additionally, average or peak temperatures are often reported, rather than duration above a specified temperature (55°C, for example). A number of suggestions have been made in the literature for minimum effective time-temperature conditions. These are based either on results of a particular study or on a review of available literature. Van Rijn and Termorshuizen (2007) recommended 60°C or more for 3 days, Veijalainen *et al*., (2005) suggested that peak temperatures should be in the range of 55 to 65°C for 3 to 14 days, and Mikkelsen *et al*., (2006) felt that composting for 21 days with peak temperatures of 64 to 70°C would ensure elimination of the majority of plant pathogens. Such temperature conditions are often seen in commercial composting systems. For this reason, Bollen (1993) concluded that composts made from diseased plant materials, possibly with the exception of TMV, are likely to be safe for use in agricultural/horticultural applications. Compost processes meeting the CCME and USEPA recommendations for human pathogens appear to consistently reduce bacterial plant pathogens to below detection limits. Adult and juvenile stages of most nematodes are apparently also sensitive to these time-temperature conditions, but more resistant nematode eggs may require higher temperatures and/or longer times for complete elimination. Bollen, (1993) suggested that

most fungal pathogens are also sensitive to temperatures of 55°C or higher. However, a number of fungal and fungus-like plant pathogens (especially those with hardy resting structures) and phytopathogenic viruses require high temperatures and extended times for eradication during composting (Mikkelsen *et al*., 2006). Thus, they may survive in systems just meeting the CCME/USEPA time-temperature requirements for removal of human pathogens. (Kristine Wichuk *et al.,* 2013)

### I.3.1.13 Compost application to agricultural soil

Composting helps to optimise nutrient management and the land application of compost may contribute to combat soil organic matter decline and soil erosion (Van Camp *et al*., 2004). Compost land application completes a circle whereby nutrients and organic matter which have been removed in the harvested produce are replaced (Diener *et al.,* 1993).The recycling of compost to land is considered as a way of maintaining or restoring the quality of soils, mainly because of the fertilizing or improving properties of the organic matter contained in them. Furthermore, it may contribute to the carbon sequestration and may partially replace peat and fertilizers (Smith *et al*., 2001).Compost application to agricultural land needs to be carried out in a manner that ensures sustainable development. Management systems have to be developed to enable to maximize agronomics benefit, whilst ensuring the protection of environmental quality. (Saleh *et al.,* 2011)The main determinant for efficient agronomics use is nitrogen availability, high nitrogen utilization in agriculture from mineral fertilizers is well established and understood, whereas increasing the nitrogen use efficiency of organic fertilizers requires further investigation (Amlinger *et al*., 2003).

### I.3.1.14 Utilization of Compost

In some countries, before 1980's, the soil fertility was maintained mainly by the use of organic fertilizers such as farmyard, manure, compost, green manure, straw and organic wastes (Kuo *et al.,* 2014). At the present, low soil organic matter content on arable lands has made them become less fertile (Kuo *et al*., 2014). The over use of inorganic fertilizers and intensive fieldcrop production can cause the quality of agricultural soils to decline. Reduced soil physical quality is, in turn, linked to declined crop performance and/or profitability, as well as negative environmental impacts related to the off-field movement of soil (wind/water erosion) and agrochemicals (pesticide/nutrient leaching into surface and ground waters) (Kuo *et al*., 2014).The beneficial effects of the use of compost can be seen in landscaping, which can be hard and soft landscaping schemes. Hard, includes road construction and motorway edges and

surfacing of landfill sites. Soft landscaping involves the utilization of compost in parks, gardens, playground and golf courses (Kuo *et al*., 2014) In horticulture and agriculture, compost can be used as an alternative to peat as a growing medium, as a source of organic matter, as a cover material to conserve moisture and suppress plant disease and also as a nutrient source (Kuo *et al*., 2014). As the quantity and quality of organic matter declines in many farming systems, farmers are now faced with finding alternative or supplementary sources of nutrients. The compound fertilizer made by compost is welcome very much at present because peasants know that too much use of inorganic fertilizers is not good to the soil and the environment (Kuo *et al*., 2014). The variety of tropical agro-ecosystems and the diversity of organic inputs used in those systems, including trees, shrubs, cover crops and composts present a challenge for research and extension activities in soil fertility management (Kuo *et al.,* 2014).

### I.3.1.15 Suppression of Plant Diseases by Composts

Application of compost can improve the soil health and its nutrient levels as well as help reduce pathogen attacks.

#### I.3.1.15.1 Role of compost in disease suppression

The utilization of composts in disease suppression was first suggested by Hoitink *et al.,* (1975). Inclusion of compost in the growing media as a method to suppress a wide variety of soil-borne plant pathogens like Rhizoctonia root rot (*Rhizoctonia solani*) on bean and cotton, Fusarium wilt (F. *oxysporum* f. sp. *cucumerinum*) of cucumber, Sclerotinia drop (*Sclerotinia sclerotium*) of lettuce etc. was studied by Lumsden *et al.,* (1983). These studies showed the importance of composts in the biocontrol of different soil-borne plant diseases ( Mehta *et al.,* 2013). Hoitink and Fahy, in 1986, reported that various types of agricultural and forestry wastes, as well as municipal wastes could be used for compost preparation and these wastes can be used in the suppression of soil-borne plant pathogens, especially those belonging to the genera *Rhizoctonia, Pythium*, *Fusarium* and *Phytophthora* ( Mehta *et al*., 2013).The studies suggested that the fungal antagonists which are most effective for control of various soil-borne plant pathogens in bark compost-amended substrates are *Trichoderma* spp., Gliocladium virens and a variety of bacterial antagonists, such as *Flavobacterium balustinum*, *Pseudomonas putida*, and *Xanthomonas maltophilia*, all of which are rapid colonisers of organic matter. This study also concluded that antagonists have long-term effects only in substrates amended with mature composts and have short-term effects or are ineffective in substrates prepared with sphagnum peats as the sole organic component. (Mehta *et al.,* 2013).

Many publications have shown the positive effects of compost application on the reduction of plant disease. Lewis *et al*., (1992) found that 3–4 years of compost treatment improved cotton stand, and also significantly reduced the inoculum density of R. solani in soil. Serra-Wittling *et al.*, (1996) reported that soil amended with municipal solid waste compost significantly reduced Fusarium wilt in flax. Szczech (1999) also reported that the addition of vermicompost to a conductive potting medium resulted in the substrate becoming suppressive to Fusarium wilt of tomato caused by F. oxysporum. The composts produced from different types of agricultural residues proved suitable for container media and field soils ( Mehta *et al.,* 2013).

Termorshuizen *et al*., (2006) conducted a study with 18 commercial composts and tested these composts in 7 pathosystems i.e. V. dahliae on eggplant (*Solanum melongena*), R. solani on cauliflower (*Brassica oleracea var. botrytis*), R. solani on pine (*Pinus nigra* var. austriaca), *Phytophthora nicotianae* on tomato (*Lycopersicon esculantum* Mill.), *P. cinnamomi* on lupin (*Lupinus spp*.), Cylindrocladium spatiphylli on spathiphyllum (Spathiphyllum wallisii Hort. cv. Ceres), and *F. oxysporum* on flax (*Linum usitatissimum*), ( Mehta *et al.,* 2013). The authors found that after applying 20% of the selected compost into potting soil or sand, 54% of the tested combinations were significantly more disease suppressive. The mean disease suppressiveness per compost ranged from 14 to 61%. In addition, compost based suppression of germination of S. rolfsii sclerotia was studied by Danon *et al*., (2007). Mature biosolids compost (a blend of sewage sludge and yard waste) was found suppressive for germination of the sclerotia on compost plates and also suppressed disease development in bean plants (*Phaseolus vulgaris* L.), (Mehta *et al.,* 2013).

Recent study reports have also shown that organic farming practices and especially compost application, may lead, with time, to some reduction of the problems caused by *F. oxysporum* f. sp. melonis (Yogev *et al.,* 2011). However, reports of the deleterious effect of prolonged compost storage on disease suppression also exist (Mehta *et al.,* 2013).

### I.3.1.16 Mechanisms for disease suppressiveness in composts

#### I.3.1.16.1 Competition among microbial populations

In every ecosystem, microbes compete for nutrients (Chen *et al.,* 1988) and space (Serra-Wittling *et al.,* 1996). Pathogens which grow or move to the sources of nutrients must also compete with the beneficial microflora in the infection court on the surface of the seed or root (Hoitink and Changa, 2004). This type of competition plays a major role in general suppression and with ‘‘nutrient dependent’’ pathogens such as Pythium and Phytophthora species, and

involves microbial competition for nutrients and competition for infection sites and root colonisation (Diánez *et al.*, 2005). A significant reduction of disease in compost amended soils was observed towards F. oxysporum f. sp. radicis-lycopersici, Pyrenochaeta lycopersici, Pythium ultimum, and R. solani (Mehta *et al.,* 2013).

Massive production of siderophores leads to reduced levels of iron which are essential for successful germination of the pathogen and penetration of the host. ( Mehta *et al.,* 2013). Fluorescent pseudomonads, well known for their siderophore production, can compete with Fusarium by suppression of Fusarium chlamydospore germination (Elad and Baker, 1985). Analyses of mutants lacking the ability to produce siderophores suggest that they contribute to suppression of certain fungal diseases (Duijff *et al*., 1994; Buysens *et al*., 1996). Thus, microbes with siderophore producing abilities can work against pathogens and can suppress their effect on crop/vegetable plants. (Mehta *et al.,* 2013). The role of Pseudomonas spp. in disease suppression is well known. Recent studies also support their role as a competitor against pathogens in soil and reduce their direct effects on plant and also help in plant growth promotion (Kyselková and Moënne-Loccoz, 2012).

**I.3.1.16.2 Antibiosis**

Antibiosis is an antagonistic process mediated by microbes through specific or non-specific metabolites, lytic agents, enzymes, volatile compounds, or other toxic substances (Jackson, 1965; Fravel, 1988). The word antibiosis refers to an association of two organisms in which one is harmed or killed by the other. Production of antibiotics by compost microbes is thought to be a mechanism for suppressiveness against pathogens, although it has not yet been proven. Antibiotic production is very common among compost microbes, and the process can be detected by inhibition of growth of pathogenic microbes in a plate assay. Different bacterial species such as *Pseudomonas* and *Bacillus* are well known for their antibiotic production properties, and for their biocontrol of several crop diseases ( Mehta *et al*., 2013).

For instance, B. cereus UW85 produces the antibiotics zwittermicin A and kanosamine, known to be important in the biocontrol of oomycetes like *Phytophthora* (Silo-Suh *et al*., 1994; Milner *et al.,* 1996). *Pseudomonas spp*., well known for their antagonistic property against *Fusarium* wilts, potato scab, apple replant disease, and take-all (Weller *et al*., 2002), are able to significantly reduce disease incidence and also protect plant roots from different infectious diseases (Haas and Défago, 2005). Trichoderma and Gliocladium are also known to be capable of the production of antimicrobial compounds that can suppress disease by diverse mechanisms

(Howell *et al*., 1993). Gliotoxin, an antibiotic produced by Gl. virens in composted mineral soil populated with natural microbiota, has been shown to effectively control damping-off of zinnia seedlings (Zinnia elegans) caused by Py. ultimum and R. solani (Lumsden *et al*., 1992). Recently Zygosporium masonii was reported as a new fungal antagonist against anthracnose disease in bell pepper caused by the pathogen Colletotrichum capsici (Ajith and Lakshmidevi, 2012).

#### I.3.1.16.3 Hyperparasitism

Hyperparasitism is a type of direct antagonism where a microorganism directly attacks a pathogen and kills it (Heydari and Pessarakli, 2010). In general, there are four major classes of hyperparasites, obligate bacterial pathogens, hypoviruses, facultative parasites, and predators. Pasteuria penetrans, a bacterial parasite known for its biological control activity against root-knot nematodes, is a perfect example of hyperparasitism (Pal and McSpadden Gardener, 2006). There are several examples of hyperparasitism in fungi where non-pathogenic microbes parasitise or lyse the mycelium, resting spores (oospores), hyphae or sclerotia of several pathogenic soil fungi such as *Pythium, Phytophthora, Verticillium, Rhizoctonia, Sclerotinia,* and *Sclerotium* (Diánez *et al*., 2005). Suppression of R. solani by *Trichoderma harzianum* is a common example of hyperparsitism (Chet and Baker, 1980). The frequent occurence of *T. harzianum* in composts is indicative of a compost where suppression of R. solani is taking place (Kuter *et al*., 1983).

Certain examples of multiple hyperparsitism also exist, where multiple hyperparasites such as *Acremonium alternatum, Acrodontium crateriforme, Ampelomyces quisqualis, Cladosporium oxysporum,* and Gl. virens together have the capacity to parasitise powdery mildew pathogens (Kiss, 2003). *Phytophthora capsici* oospores, known for their wide host range including Cucurbitaceae, Fabaceae, and Solanaceae families, are parasitised by beneficial actinomycetes and fungal species such as *Acremonium* spp., *Humicola fuscoatra* and *V. chlamydosporium* (Sutherland and Papavizas, 2008). Therefore, hyperparasites can control populations of many pathogens that play a major role in crop diseases (Fodor, 2011).

#### I.3.1.16.4 Systemic acquired resistance (SAR) and induced systemic resistance (ISR)

Systemic acquired resistance (SAR) and induced systemic resistance (ISR) are two forms of induced resistance to pathogenic attack. In both SAR and ISR, plant defenses are preconditioned by prior infection or treatment that results in resistance (or tolerance) against a

pathogen or parasite (Vallad and Goodman, 2004). In general, SAR and ISR are defined as a state of enhanced defensive capacity developed by a plant when appropriately stimulated (Bakker *et al*., 2003). Great advances have been made over the past few decades to understand the physiological and biochemical basis of SAR and ISR. SAR can be induced by chemicals, pathogens, and beneficial soil microorganisms (Maurhofer *et al*., 1994; Pieterse *et al*., 1996; De Meyer and Höfte, 1997). A variety of microbes present in compost amended substrate are capable of inducing systemic resistance in plants (Wei *et al*., 1991; Liu *et al.,* 1995). Interaction of the compost and pathogen infection is considered a critical factor for rapid activation of SAR-associated gene expression in cucumber plants grown in compost mix (Zhang *et al*., 1996). On the other hand, ISR is referred to as one of the most important mechanisms through which compost induces disease resistance to plants (Mehta *et al.,* 2013). Many bacterial and fungal isolates have been reported to turn on an ISR property in plants (van Loon *et al*., 1998).

The microbial communities in composts are also known for triggering anatomical changes in plants (Pharand *et al.,* 2002). Composted pine bark was found to be suppressive to Pythium root rot of cucumber and it was suggested that the resistance mechanism was systemic and related to enzymatic or hormonal activities (Zhang *et al.,* 1996). Expression of pathogenesis-related (PR) genes in compost amended roots of tomato plants was studied and it was found that PR genes were expressed by plants even in the absence of pathogens. It was concluded that the expression of PR genes may be triggered by the microflora of the compost or could be associated with abiotic characteristics of the compost (Kavroulakis *et al*., 2006). A study of Sang and Kim (2011) indicated a compost mediated ISR property. The authors reported that a water extract from compost significantly reduced anthracnoses caused by Colletotrichum coccodes on pepper leaves and Colletotrichum orbiculare on cucumber leaves (C.M. Mehta *et al.,* 2013).

**I.3.1.16.5.Ineffective pathogen proliferation**

Usually, a pathogen propagule does not proliferate in the absence of a host (Lockwood, 1990). Chemical signals from the root or shoot exudates are required for host identification by the pathogen (Chen *et al*., 1988), but compost containing media can mimic these signals and trigger the germination of a pathogen before it comes in contact with its host. This is a probable reason behind the effectiveness of plant generated composts against soil-borne disease (Cheuk *et al.,* 2005) and the reduction of pathogen activity level, even in the absence of plants (Yogev *et al.,* 2006). A study of Cheuk *et al.,* (2005) reported a significant reduction of Fusarium crown and

root rot in tomato seedlings applied with compost amendment from several different batches, as a seed cover or plug substitute.

#### I.3.1.16.6 Physicochemical properties of compost

Several reviews suggested that the physicochemical properties of composts, namely nutrients and organic molecules such as humic, phenolic or bioactive compounds (Siddiqui *et al.,* 2008; Spatafora and Tringali, 2012), may protect plants against disease through improved nutritional status, direct toxicity toward the pathogen or induced systemic resistance. (Mehta *et al.,* 2013).

### I.3.1.17 Benefits of composting

During the composting process, organic materials are decomposed by microorganisms under low moisture, aerobic conditions, resulting in a nutrient rich product that can be used as a replacement for peat, fertilizers and manure in agricultural and horticultural activities, such as landscaping, home gardening, and erosion control (Levis *et al.,* 2010; Okafor, 2011; USEPA, 2011). In addition, Composting decreases environmental problems related to waste management by reducing waste volumes and by killing potentially dangerous organisms. The agricultural utilization of compost could meet the target objective of European Union countries to decrease the quantity of organic waste going to landfill sites by 20% by 2010 and by 50% by 2050. According to Saer *et al* in 2013, several studies have shown the environmental benefits of compost use for improving soil quality, including: 1) incorporation of organic matter, nutrients and electrolytes into the soil, 2) reducing the need for fertilizer, pesticides and peat use, 3) improvements in soil structure, density and porosity, which increases water retention capacity and reduces erosion and nutrient leaching, and 4) enhanced carbon storage capacity in the soil, thus, reducing global warming (Favoino and Hogg, 2008; Martínez-Blanco *et al*., 2009; ROU, 2007).

## I.4 Generality on cassava peels

Cassava (*Manihot esculenta Crantz, Euphorbiaceae*) is the sixth most important food crop globally, in terms of annual production, and is a staple food for approximately 800 million people (Kortei *et al*., 2014). This perennial root crop is grown in the tropics, including sub-Saharan Africa, Asia, the Pacific Islands, and Central and South America (Kortei *et al*., 2014). Cassava is cultivated in more than 100 countries worldwide (Stephanie *et al.,* 2012). It holds the position of the strategic crop in many tropical countries, (Stephanie *et al.,* 2012) such as Cameroon. In Cameroon, it is a leading crop in terms of annual yield both for cash and food

crop categories. It is widely consumed and processed far beyond other crops such as maize and rice (Stephanie *et al*., 2012). Cassava is cultivated for its starchy roots and is a staple food material in many developing countries, including Cameroon, where it is eaten as garri, fufu, or other products. According to the Central Bureau of Statistics in 2004-2008, the production of cassava peel tend to increase annually which means the production of cassava peel also increasing (Suci *et al.,* 2017). Cassava peel is the peeling of food product from cassava. The Chemical composition of cassava peel is identic with cassava which contains most of the polysaccharide and some of mineral and water.

The main component of polysaccharide is amylose, amylopectin, and cellulose (Suci *et al*., 2017). Cassava peel represents about 5 to 15% of the root when peeled mechanically (Aro *et al*., 2010) and about 20 – 35% of the weight of the tuber with hand peeling (Odunfa *et al* ., 2012). The solid fibrous dry waste consists of 56 – 60% starch, 15 – 18% hemicellulose, 2 – 3% lignin, 1.5 – 2% protein, 2% pentosan and 0.4 –5% reducing sugar (Wongskeo *et al.,* 2012) making it a good organic matter of composting. During the processing of cassava tubers, an enormous quantity of cassava peels (about 30% of processed cassava tubers) are generated as waste (Adebayo *et al*., 2005) and only an insignificant proportion is usually fed to livestock such as goats (Odediran *et al*., 2015). Very often, cassava peels are thrown away after removal from the edible part of the root during processing. The peel eventually decays in the soil (Makinde *et al*., 2017). However, The potential of these peels to be used in the production of other products such as biofertilizers can help most of the cassava processors and farmers to increase their source of income, to avoid the environmental nuisance released by cassava peels on dumping sites and the pollution of both water and land resources, which might increases rodents and insect vector diseases thereby creating public health nuisance.

## I.5 Biopesticide

### I.5.1 Definition

Biopesticides derived from natural materials such as animals, plants, bacteria and certain minerals. These are divided into 3 major classes: Microbial pesticides, Plant Incorporated Protectants (PIPs) and biochemical pesticides.

### I.5.2 Concept of biopesticides

Bio-pesticides are naturally occurring substances from living organisms (natural enemies) or their products (microbial products, phytochemicals) or their by-products (semiochemicals) that

can control pest by nontoxic mechanisms (Salma and Jogen, 2011). According to the Organization for Economic Co-operation and Devlopment (2009), biopesticides are manufactured mass produced agents derived from natural sources living micro-organisms and sold for use to control pests. According to Suman and Dikshit (2010), biopesticides encompass a broad array of microbial pesticides, biochemicals obtained from micro-organisms and natural sources.

They do not have any residue problem, which is a matter of substantial concern for consumers, specifically for edible fruits and vegetables. When they are used as a constituent of insect pest management, the efficacy of biopesticides can be equal to that of conventional pesticides, particularly for crops like fruits, vegetables, nuts, and flowers. By combining synthetic pesticide performance and environmental safety, biopesticides execute efficaciously with the tractability of minimum application limitations and with superior resistance management potential (Kumar, 2012; Senthil-Nathan, 2013).

Biopesticides have been gaining attention and interest among those concerned with developing environmentally friendly and safe integrated crop management (ICM)-compatible approaches and tactics for pest management (Copping *et al.,* 2000). Farmers' adoption of biopesticides may follow the recent trend of "organically produced food" and the more effective introduction of "biologically based products" with a wide spectrum of biological activities against key target organisms, as well as the developing recognition that these agents can be utilized to replace synthetic chemical pesticides (Copping *et al*., 2000; Chandrasekaran *et al*., 2012; SenthilNathan, 2013). Compared with chemical pesticides, biopesticides do not present the same regulatory problems seen with chemical pesticides. Biopesticides are frequently target specific, are benign to beneficial insects, and do not cause air and water quality problems in the environment, and also agricultural crops can be reentered soon after treatment.

### I.5.3 Categories of biopesticides

#### I.5.3.1 Microbial Pesticides

It is microorganisms such as bacterium, virus, fungus, protozoan as active ingredients which are used for the biological control of plant pathogens, pestiferous insects and weed. The most widely used microorganism in the development of biopesticide is the insect pathogenic bacterium Bacillus thuringiensis (Bt). This bacterium serves as an insecticide for most Lepidoptera, coleopteran and diptera (Gill *et al*., 1992). B. thuringiensis produces protein

crystals or toxin during spore formation of the bacterium that is capable of lysis of gut cells when consumed by a specific or susceptible insects (Chandler *et al*., 2011).

### I.5.3.2 Biochemical Pesticides

They are also known as herbal pesticides (Pal and Kumar, 2013) are naturally occurring substances used for controlling pests through a non-toxic mechanism. The application of naturally occurring substances to control pests by non-toxic means is an important distinction of this class from pesticides of plant origin (botanical pesticides) which can kill the pest by toxic means e.g. pyrethrins (Koul *et al.,* 2001). Biochemical pesticides may originate from plants, animals or insects. The common examples of this category include pheromones from insects and secondary metabolites from plants. (Anselm P.Moshi *et al.,* 2016).

#### I.5.3.2.1 Botanical biopesticides

Botanical biopesticides derived from a variety of plant parts such as leaves, barks, seeds, spices, flowers or roots. Botanical based biopesticides are widely utilized as crop protectants for both field and storage pests. Significant number of studies have reported on the use of botanical biopesticides against crop pests for example. the treatment of chilli seeds with oil of *Ocimum sp*. completely inhibited the development of fungi during 12 months of storage (Amrita *et al*., 1989), methanolic extracts of medicinal plants against wheat pest, Tribolium castaneum Herbst (Padín *et al.*, 2013), and Phthorimaea operculella Zeller against the potato tuber moth (Thakur and Chandla, 2013). Others include essential oils from plant (Rugumamu, 2014; Anselm P.Moshi *et al.,* 2016).

In general, there are significant differences in the mode of action between microbial and botanical pesticides: living organisms and natural products. In fact, Living organisms act by exploitation, competition, antibiosis, lysis and/or induced resistance, while natural products act by contact, ingestion, systemic action, suffocation and/or attraction/ repulsion.

Compounds from natural products, have minimum adverse effects on the physiological processes of plants and are easily convertible into common eco-friendly organic materials (Gnanamanickam, 2002).

Plant extracts have been shown to exert biological activity against plant fungal pathogens in vitro and in vivo and can be used as bio-fungicidal products (Fawzi *et al.,* 2009; Jalili *et al*., 2010; Romanazzi *et al.,* 2012). These products are generally assumed to be more acceptable

and less hazardous for the ecosystems and could be used as alternative remedies for treatment of plant diseases (Chuang *et al.,* 2007).

Natural plant products have a narrow target range with specific mode of action, therefore are suitable for a specific target, mostly nontoxic for antagonistic microorganisms, show limited field persistence and have a shorter shelf life and no residual threats. They often constitute a part of integrated pest management (IPM) programs, generally safe to humans and environment in comparison to conventional synthetic chemical pesticides. They can easily be adopted by farmers in developing countries who traditionally use plant extracts for the treatment of human diseases (Nuzhat and Vidyasagar, 2013).

It is estimated that there are more than 250,000 higher plant species on the earth offering a vast virtually untapped reservoir of bioactive chemical compounds with many potential uses, including their application as pharmaceuticals and agrochemicals (Cowan, 1999). As in pharmacology, bio-chemicals isolated from higher plants may contribute to the development of natural products for the agricultural industry in three different ways: 1) - by acting as natural pesticides in an unmodified state (crude extracts), 2) - by providing the chemical 'building blocks' necessary to synthesize more complex compounds and 3) - by introducing new modes of pesticidal action that may allow the complete synthesis of novel products in order to counter the problem of resistance to currently used synthetic products by plant pathogenic fungi and bacteria (Cox, 1990).

Many reports approve the efficacy of natural products of plants in controlling fungal growth and mycotoxin production, (Marin *et al*., 2004). But the mechanism of action of plant compounds against fungi is not completely understood but it is supposed to be in relation to their general ability to dissolve or otherwise disrupt the integrity of fungal cell walls and cell membranes (Isman and Machial, 2006).

### I.5.4 Effects of synthetic pesticides and biopesticides on food, public health and the environment

For compound to be considered biopesticide and be released for use in organic crops must undergo a series of toxicological tests.(European Food Safety Authority, 2015). Most of the pesticides approved for organic agriculture are of comparatively low toxicological concern for consumers because they are not associated with any identified toxicity, this because the raw materials used for the production of biopesticides are part of the human diet (for example, iron and potassium bicarbonate, peppermint oil, among others) (J. A. Vieira Costa *et al*., 2019)

In addition, biopesticides are typically designed to affect only the target pest or groups of specific organisms (J. A. Vieira Costa *et al*., 2019) and they are different from the synthetic pesticides that do not exhibit specificity in their performance. Therefore, synthetic pesticides besides present toxicity to the pests and pathogens contaminants of plant crops can also affect negatively humans, animals and the environment (J. A. Vieira Costa *et al*., 2019)The toxicity of synthetic pesticides, biochemically, is given by inhibition of enzymes, modification in the signaling system, disturbance in electrolytic equilibrium, osmotic or pH, degradation of lipophilic membranes and pH gradients across membranes, in addition to the generation of free radicals and other substances that can destroy tissues, DNA and proteins of organisms. (J. A. Vieira Costa *et al*., 2019)

Due to the mechanisms of action of synthetic pesticides and the increased exposure of humans to these substances, in recent years the use of these products has been linked to the increase of some diseases, including Parkinson's disease, (Maele-Fabry *et al*., 2012) type 2 diabetes,(Starling, A. P *et al.*, 2014) certain types of cancers, (Ntzani *et al.*, 2013) endocrine disruption,( Kortenkamp *et al.*, 2014) neurotoxicity (Bjørling-Poulsen *et al*., 2008) and even obesity.(Araujo *et al*., 2016). The most of the currently used pesticides are rapidly excreted, but there are still some pesticides used that accumulate in the human body at every meal consumed,(Carvalho *et al.*, 2017) besides this there are proven cases of workers exposed directly to the spray of pesticides who are intoxicated by these substances.(Rodrıguez *et al*., 2017) The environment has also been affected by the use of synthetic pesticides, since less than 5% of the products applied in the plantations reach the target organisms, which put at risk the sustainability of the ecosystems. Pesticide residues can leach the subsoil and contaminate groundwater, ( Al-Abboud *et al.*, 2014) as well as accumulate toxic levels in the soil by destroying natural vegetation and reducing populations of non-target organisms such as bees, fish, wildlife and livestock.(Aktar *et al.*, 2009) It is also important to emphasize that the continuous use of synthetic pesticides makes them more resistant pests, necessitating the use of higher concentrations of product and consequently greater toxicity,(Pimentel et al., 2005) resurgence and outbreak of new pests.( Singh *et al* ., 2018).

### I.5.5 Biopesticides application technology/methods

Effective control of pests can be achieved by good selection of application techniques/methods and an appropriate time and/or frequency of biopesticides application. The following are some of the methods of biopesticides application (Tijjani, A *et al.*, 2017):

### I.5.5.1 Seed Treatment

One way to apply biopesticides is by seed treatment and is the most effective method or technique. Powder formulations are applied on seeds by tumbling seed with the product that is designed to adhere to the seed (Matthew *et al.,* 2014).

### I.5.5.2 Foliar Application

Simply means biopesticides application on leaves surface as sprays. For example application of B. subtillis to bean leaves reduced the incidence of bean rust caused by Uromyces phaseoli. (Tijjani, A *et al*., 2017):

### I.5.5.3 Seedling Dipping

This involves dipping roots of the seedlings in biopesticides suspension for some minutes or hours prior to transplanting. For example Trichoderma spp. are applied in this way. (Tijjani, A *et al*., 2017).

### I.5.6 Mechanisms of action of biopesticides for pest control

The mechanisms of action of biopesticides for pest control include the following:

### I.5.6.1 Antibiosis

This occurs as a result of an interaction with other microbes (microorganisms) mediated by specific metabolite of microbial origin, by volatile compounds, lytic enzymes or other toxic substances (Rikita and Utpal, 2014). The microorganisms produce antibiotics, bacteriocin, volatile compound and metabolite production.

### I.5.6.2 Competition

Another mechanism of control by biopesticides is their ability to compete aggressively, that they grow rapidly and colonize substrate to exclude pathogens. For example Trichoderma spp are aggressive competitors of Fusarium spp.

### I.5.6.3 Hyperparasitism

Hyperparasitism is the lysis of the death by other microorganisms or direct parasitism. For e.g T. lignorum is found to be parasitizing the hyphae of R. solani and therefore soil inoculation with Trichoderma spores help to control damping off disease in citrus seedlings (Rikita and Utpal, 2014).

### I.5.6.4 Synergism

The ability of some bioagent to combine actions of hydrolytic enzymes and antibiotic secondary metabolites. For example the effectiveness Trichoderma spp. as a biocontrol agent and its fitness in the environment is as a result of synergistic effects of antimicrobial compounds. Example includes pyrones, coumarins etc.

### I.5.7 General advantages of biopesticides

Biopesticides are usually inherently less harmful/toxic and cause less environmental load or pollutions. Designed to only one specific pest or, in some cases, a few target pests as opposed to chemical that have a broad spectrum activity. The cost of developing biopesticides is significantly lower than those of synthetic chemical pesticides. Their nature of control is preventive not curative and their effects on flower is less (Tijjani, A *et al*., 2017).

### I.6 Generality on *ocimum gratissimu* L

*Ocimum gratissimum L*. commonly known as clove basil belonging to family Lamiaceae is an important aromatic and medicinal plant existing wild or cultivated in various tropical and subtropical parts of the globe. The plant possesses two unique features firstly it contains essential oil with diversity in chemical composition and water stress tolerance capacity (Sandeep pandey *et al.,* 2017). In Cameroon, it is commonly known as large-leaved basil, or also "Massep" (Béti) and "Ourdi soulabé" (Fufuldé). Probably native to Asia, *O. gratissimum* is now widespread throughout tropical Africa. In Cameroon, it is found around houses (Pousset, 1989) and is a flavoring regularly used with *Ocimum basilicum* as a substitute (Noumi, 1984). In addition, the juice of the leaves of *O. gratissimum* is used to relieve headaches, colds, dizziness and coughs in children (Tchoumbougnang, 1997). However, There are many species of *Ocimum*, which have their different morphological or anatomical characters. They are found in different places and have different living conditions; so that they have different medicinal value. Content of secondary metabolites also differs species to species. Different species of *Ocimum* are *Ocimum americanum, Ocimum basilicum, Ocimum campechianum, Ocimum centraliafricanum, Ocimum gratissimum, Ocimum kilimandscharicum, Ocimum minimum, Ocimum viride, Ocimum suave, Ocimum ovatum, Ocimum selloi, Ocimum tenuiflorum and Ocimum citriodorum* (Joshi *et al*., 2011; Sheelu *et al*., 2017)

### I.6.1 Morphology and microscopy

#### I.6.1.2 Morphology

*Ocimum gratissimu* is a shrub up to 1.9m in height with stems that are branched. The leaves measure up to 10 x 5 cm, and are ovate to ovate-lanceolate, sub-acuminate to acuminate at apex, cuneate and decurrent at base with a coarsely crenate, serrate margin, pubscent and dotted on both the sides ( K.S. Prabhu *et al*., 2009 ).. The leaves show the presence of covering and glandular trichomes. Stomata are rare or absent on the upper surface while they are present on the lower surface. Ordinary trichomes are few, while the long ones up to 6-celled are present on the margins mostly; the short ones which are 2 celled, are mostly found on the lamina. Petioles are up to 6 cm long and racemes up to 18 cm long. The peduncles are densely pubescent. Calyx is upto 5mm long, campanulate and 5-7 mm long, greenishwhite to greenish-yellow in colour. Nutlets are mucilaginous when they are wet ( K.S. Prabhu *et al*., 2009 ).

**Figure 7**: Plant of *Ocimum gratissimu* (taken by Onguene dieudonne)

#### I.6.1.3 Microscopy

The 2 surfaces of the leaf epidermal cells are typical of irregular contours, and diacytic stomata, secretory glands most abundant in the leaf, are also present in simple pluricellular hairs on the leaf veins. The cross section shows the epidermis monoestratificada (beam), a layer of

parenchyma fenced in sub-epidermal position, followed by parenchymal pond, and finally the epidermis monoestratificada lower (K.S. Prabhu *et al*., 2009).

### I.6.1.4 Botany of *Ocimum gratissimum L*. (Sheelu *et al*., 2017)

**Table 2**: Botanical classification of *Ocimum gratissimum L*

| **Botanical classification of *Ocimum gratissimum L*** | |
|---|---|
| Kingdom | Plantae |
| Division | Magnoliophyta |
| Class | Magnoliopsida |
| Order | Lamiales |
| Family | Lamiaceae |
| Genus | *Ocimum* |
| Species | *O. gratissimum* |
| Subfamily | Nepetoideae |
| Tribe | Ocimeae |
| Botanical name | *Ocimum gratissimum L* |

### I.6.1.5 Chemical composition:

Chemical composition analysis of the essential oil of *O. gratissimum* shows that it is as rich in hydrocarbon monoterpenes as in oxygenated monoterpenes, with the major compounds being thymol (46.20%) and γ-terpinene (20 , 00%) (Tchoumbougnang, 1997). Kamini in 2005 demonstrated the presence of sterols, polyphenols and sugars in the methanol extract of *O. gratissimum* (Table 3).

**Table 3**: List of biologically active compounds that have been isolated from o. *gratissimum*

| Class | Part Used | Compounds | References |
|---|---|---|---|
| Essential oil | Plant | Thymol, eugenol, methyl chavical | Nadkarni ***et al.,*** 1999 |
| Essential oil | Plant | Gratissimol | Satyavati *et al.,* 1987 |
| Mucilage | Seed | Pentoses, hexoses, uronic acid and lipids | Tharanathan *et al* .,1975 |
| Phytochemical evaluation | Plant | Alkaloids, tannins, flavonoids and oligosaccharides | |
| Essential oil | Leaves | Eugenol, methyl eugenol, cis-ocimene, trans-ocimene, pinene, camphor, germacrene- D, trans-carypohyllene, farnesene and l-bisabolene | Matasyoh *et al*., 2007 |
| Essential oil | Leaves | Eugenol, bisaboline and thymol | Janine *et al***.,**2005 |
| Essential oil | Seed | Thymol and eugenol | Iwalokun *et al***.,** 2003 |
| Essential oil | Plant | thymol, p-cymene, terpene and trans sabiene hydrate | Kéita *et al* **.,**2000 |
| Essential oil | Plant | Eugenol, 1,8 cineole, linalool, methyl chavicol , methyl eugenol | Lawrence *et al.,* 1997 |
| Essential oil | Aerial parts | Eugenol, linalool, limonene, methyl eugenol, -caryophyllene, farnesene, -terpineol,- -salinene, methyl isoeugeneol, geraniol, -copaene, bisabolol, - | Pandey *et al.,* 2000 |

| | | | |
|---|---|---|---|
| | | pinene, p-cymene, fenchone, cubenene, camphene, T-cadinol, -eudesmol, sabinene, myrcene, - bisoboline, -humelene and -elemene | |
| Essential oil | Aerial parts | Eugenol | Terezinha *et al.*, 2006 |
| Essential oil | Leaves | Citral, ethyl cinnamate, eugenol, linalool and thymol | Dubey *et a*l., 1997 |
| Volatile oils | Leaves | Thymol, -terpinene, p-cymene, limonene, terpinolene and 1,8-cineole | Jirovetz *et al* **.,** 2005 |
| Phytochemical evaluation | Aqueous extract | Tannins,steroids,triterpinoids,carbohydrates, | Offiah *et al***.,** 1999 |
| Essential oil | leaves | oleanolic acid | Njoku *et al* **.,** 1997 |

### I.6.2 Cultivation of *Ocimum gratissimum*

Throughout the tropical and subtropical regions, *O. gratissimum* is found both wild and cultivated. Most culinary and ornamental basils are of species *Ocimum*, but other species are also grown (Matias *et al*., 2010; Sheelu *et al*., 2017). This herb is harvested at full bloom for extraction of essential oils from the flowering tops. Basil is very sensitive against cold, with best growth measure in hot and dry conditions. It is best grown on drained soil (Lerner *et al*. 1996; Sheelu *et al*., 2017), which is slightly acidic with pH ranging from 5.5-6.5. The minimum temperature in which it can be grown properly is 17 °C and the maximum temperature is 39.2 °C. It requires relative humidity of 94%. In northern Europe, Canada, northern states of U.S., and south island of New Zealand, the climate is very cold, therefore *Ocimum gratissimum* is grown in a green house, and then it is planted out in late spring or early summer. *Ocimum gratissimum* is grown commercially by home gardeners and by gourmet cooks. Once a stem produces flowers, foliage production stops on that stem and becomes woody. The production of essential oil declines (Sheelu *et al*., 2017). To prevent this, a basil-grower may pinch off any flower stems before they are fully mature. Once the plant is allowed to flower, it may produce seed pods containing small reddish black seeds, which can be saved and planted in upcoming years. Use of raised-beds with plastic row covers is preferred to avoid weeds (Sheelu *et al.,* 2017). These practices can improve soil drainage, conserve water, reduce the need for weed control and keep soil from splashing into leaves (Loughrin *et al*., 2001; Sheelu *et al*., 2017)

### I.6.3 Ethnopharmacology

#### I.6.3.1 Traditional uses

*O. gratissimum* has been used extensively in the traditional system of medicine in many countries. It is used for medicinal, condiment and culinary purpose. The flowers and the leaves of this plant are rich in essential oils so it is used in preparation of teas and infusion (Rabelo M *et al*., 2003). *O. gratissimum* is used in the treatment of epilepsy, high fever and diarrhoea (Effraim KD *et al*., 2003). In the Savannah areas decoctions of the leaves are used to treat mental illness (Akinmoladun *et al*., 2007). *O. gratissimum* is used by the Ibos of Southeastern Nigeria in the management of the baby's cord, to keep the wound surfaces sterile. It is also used in the treatment of fungal infections, fever, cold and catarrh (Ijeh II *et al*., 2005). Brazilian tropical forest inhabitants use a decoction of *O. gratissimum* roots as a sedative for children (Cristiana M *et al.,* 2006). People of sub Saharan African communities' use this plant for various purposes like viz., the leaves are rubbed between the palms and sniffed as a treatment

for blocked nostrils, they are also used for abdominal pains, sore eyes, ear infections, coughs, barrenness, fever, convulsions, and tooth gargle, regulation of menstruation and as a cure for prolapse of the rectum (Matasyoh LG *et al.,* 2007).

The leaf extract is used in treatment of diarrhoea, while the cold leaf infusions are used for the relief of stomach upset and haemorrhoids (Kabir OA *et al*., 2005). The plant is commonly used in folk medicine to treat different diseases such as upper respiratory tract infections, diarrhoea, headache, diseases of the eye, skin diseases, pneumonia, cough, fever and conjunctivitis (Adebolu *et al*., 2005). The infusion of *O. gratissimum* leaves is used as pulmonary antisepticum, antitussivum and antispasmodicum (K.S. Prabhu *et al*., 2009).

### I.6.3.2 Plant pathogens

Essential oil obtained from *O. gratissimum* is a strong antifungal agent against plant pathogens as proved in various studies. As a natural product, they can be utilized to the management of a variety of pests in vegetable, cereals and stored grains. Several studies observed that plant oil exhibit a remarkable inhibition of A. niger causal organism of black mold in vegetable and fruit (Akinyemi *et al*., 2005), R. Solani, a soil-borne plant pathogenic fungus (Sethi S *et al.,* 2013) and F. oxysporum f. sp lycopersici and eight other phytopathogenic fungi (Mohr FBM *et al*., 201).

The ethanolic extract of aerial parts of the plant provides evidence of suppressing plant pathogens, Rhizoctonia sp., Botryosphaeria rhodina and two strains of Alternaria sp. (Alternaria sp. (A1) and Alternaria sp. (A2)-tomato wilt fungi) which are mainly due to the presence of eugenol a phenolic compound with fungitoxic properties. Further, this eugenol tested for anti-fungal action expresses significant control of Alternaria sp. (A1) and Penicillium chrysogenum (Faria TdeJ *et al.,* 2006). The fresh leaves oil expresses strong efficacy against mycoflora Aspergillus flavus, A. niger, A. ochraceus, A. parasiticus, Fusarium solani, F. oxysporum, F. graminearum and Mucor sp with a minimal fungicidal concentration ranging between 5.5 to 8.0 µl/ml (Adjou ES *et al.,* 2017) while other study supported methanolic leaf extract being effective against A. niger (Mishra RP *et al.,* 2015). The plant extract can act as a promising fungitoxic agent against molds P. citrinum and mycoflora C. sphaerospermum (Bankole SA *et al*., 2010), whereas the plant essential oil shows remarkable inhibition of Alternaria padwickii and Bipolaris oryzae, the seed-borne fungi of rice, remaining active even up to six days of storage (Nguefack J *et al*., 2007). The plant oil with eugenol as the main ingredient exhibits a strong anti-fungal action against F. verticillioides (Dambolena JS *et al*., 2010); and also

suppresses fumonisin contamination level in closed conditions in Maize (Fandohan *et al.*, 2004). *O. gratissimum* leaf ash shows strong potentiality in inhibiting germination of Sclerotium rolfsii, a soil-borne facultative pathogen in wheat (Enikuomehin *et al*., 1998).

Plant oil has shown promising inhibitory action against three food spoilage and mycotoxin fungi, F. moniliforme, Aspergillus fumigatus and A. flavus and remains stable even in changing pH environment hence making it an important food preservative (Nguefack J *et al.*, 2004). A study reported that the plant oil possess shelf life enhancer property and can act as an anti-aflatoxigenic agent against aflatoxin and fungal contamination of spices with the potentiality to restrict aflatoxin B1(AFB1) formation of A. flavus (Prakash B *et al*., 2011). The volatile oil also exhibits an effective food preservation property as reflected by various researchers. The pH and concentration-dependent study conducted on fungicidal activity of EO on mycotoxigenic strains each from P. expansum, A. ochraceus and P. verrucosum reveals a strong activity against these strains (Nguefack J *et al*.,2009) The investigation on efficacies of six essential oils against Aspergillus, Penicillium, Fusarium and Scopulariopsis genera for preservation of cheese wagashi reported *O. gratissimum* as the second best essentials oil in suppressing these molds (Jedlickova *et al*.,1992).

### I.6.4 Pharmacological studies

#### I.6.4.1 Antifungal activity

An antifungal activity is found in the essential oil that can be obtained by steam-distillation (1.1% w/v) of the aerial parts of *O. gratissimum*. (Sheelu *et al*., 2017). The results showed that the essential oil inhibit the growth of all fungi tested, including the phytopathogens, Botryospaeria rhodina, Rhizoctonia sp. And two strains of Alternaria sp. (Prabuseenivasan *et al*., 2006; Sheelu *et al.*, 2017). Ethanolic, hot water and cold water extract of *O. gratissimum* was tested against Colletotrichum species isolated from spoilt tomatoes. Maximum zone of inhibition was measured in case of hot water extract and then in ethanolic extract and least in cold water extract (Orji *et al*., 2015; Sheelu *et al*., 2017). Antifungal activities against, Microsporum canis, M. gypseum, Trichophyton rubrum and T. mentagrophytes. Trichophyton rubrum, the most common dermatophytes in Brazil was carried out and found that hexane extract of *O. gratissimum* and eugenol is very effective against the dermatophyte (Silva *et al*., 2010; Sheelu *et al*., 2017).

### I.6.4.2 Antibacterial activity

Different extracts from the leaves of *Ocimum gratissimum*, show antibacterial activity when tested against Staphylococcus aureus, Salmonella typhi and Salmonella typhimurium, pathogenic bacteria which causes diarrhea. Extract included cold water extract, hot water extract and steam distillation extract (Sheelu *et al*., 2017). Only steam distillation extract has inhibitory effects on the selected bacteria and the minimum inhibitory conc. ranged from 0.1% for S. aureus to 0.01% for E. coli and S. typhimurium, and 0.001% for S. typhi (Adebolu *et al*., 2005). *Ocimum gratissimum*, ethanolic extract was tested for anti-microbial activity against Actinobacillus actinomycetemcomitans in human dental plaque and compared with 0.2% chlorhexidine as the positive control and dimethyl sulfoxide (DMSO) as the negative control. Maximum antimicrobial potential was at 0.6% concentration level (Eswar *et al*., 2016). Antimicrobial activity was carried out against Aggregatibacter actinomycet emcomitans, Prevotella intermedia, and Porphyromonas gingivalis and found that 0.5 and 1.0 % extract showed maximum zone of inhibition. Doxycycline was taken as positive control and DMSO as negative control (Mallikarjun *et al*., 2016; Sheelu *et al*., 2017).

## I.7 Secondary metabolites involved in plants

Plants are sites for an intense metabolic activity leading to the synthesis of primary and secondary metabolites. These metabolic processes are related to living conditions of the plant itself, which has to face multiple aggressions from the environment in which it lives: predators, pests, phytopathogenic microorganisms, etc. It is therefore conceivable that the plant can develop a particular metabolism resulting in the synthesis of various active molecules (secondary metabolites). Secondary metabolites are classified according to several criteria: their synthetic pathways, chemical characteristics or their carbon skeleton. Thus, several families of secondary metabolites participate in plant defence reactions to different biotic and abiotic stresses.

### I.7.1 Polyphenols

A widely distributed group of natural compounds characterized in plants that belong to the family of phenolic compounds or polyphenols. They share one or more benzene rings bearing at least one hydroxyl group. Most are derived from phenylalanine and to a lesser extent from tyrosine (mainly involved in monocotyledons) (Figure 8 A). These amino acids are synthesized from the shikimic acid pathway and whose precursors are intermediate

molecules derived from the pentose phosphates (D-erythrose-4-phosphate) or glycolysis pathway (phosphoenolpyruvate) (Benhamou, 2009). The commitment's step of the shikimic acid pathway is catalyzed by the enzyme's phenylalanine aminolyase and cinnamate hydroxylases. According to the number of phenolic units, complexity of the carbon skeleton, degree of modification ( hydroxylation, methylation), and the possible links with other metabolites (lipids, proteins), polyphenols are grouped into several classes (Figure 8 B).

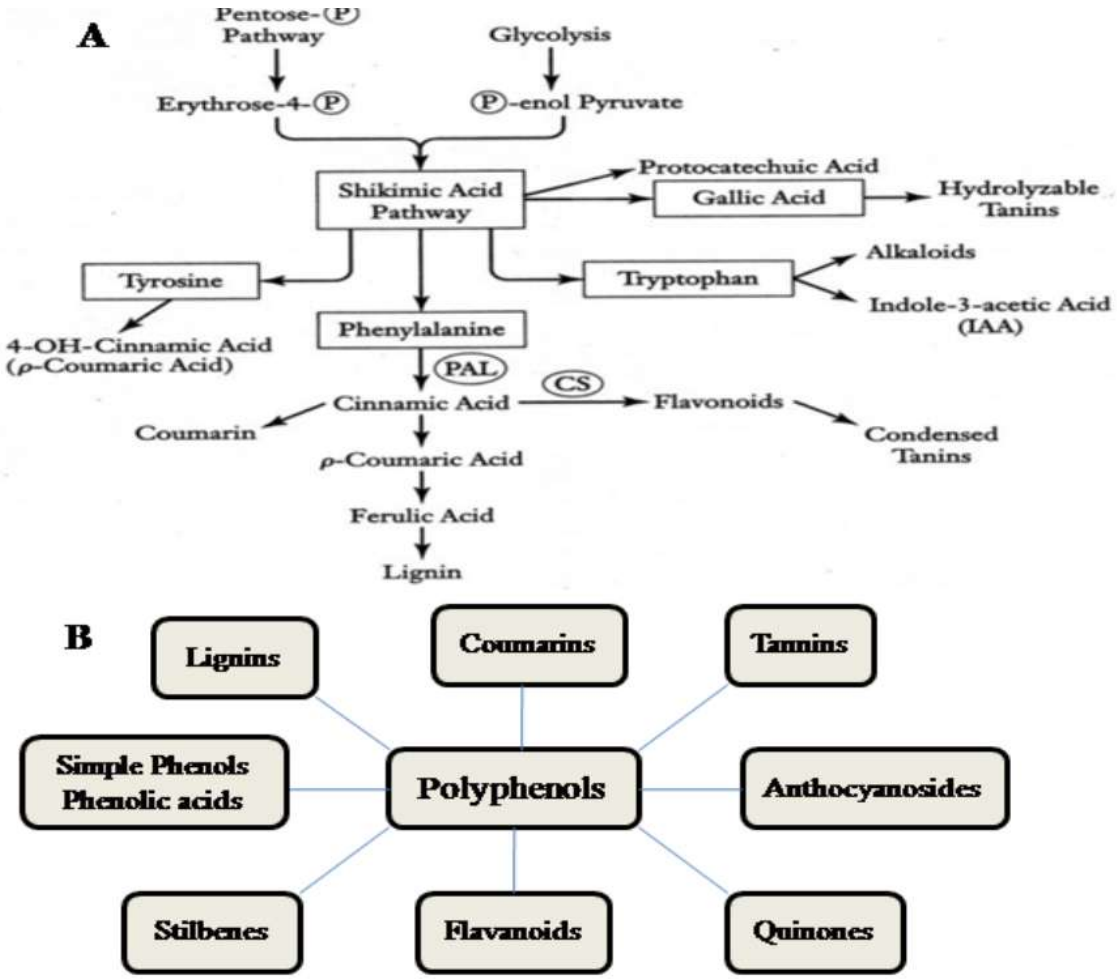



**Figure 8:** Biosynthesis (A) and classification (B) of polyphenols

Mainly comprising of simple phenols and phenolic acids, stilbenes, flavonoids, hydrolysable and condenses tannins, coumarins, lignins, and xanthones (Stalikas, 2007). Polyphenols (phenolic acids, tannins, and flavonoids) are the most important group of phytochemicals in plants (Beta *et al*., 2005).

### I.7.1.1 Phenolic acids

Phenolic acids are characterized by their basic skeleton consisting of an aromatic ring connected to 1 carbon atom ($C_6$-$C_1$) for the hydroxybenzoic acids or to 3 carbon atoms ($C_6$-$C_3$) for the hydroxycinnamic acids (Sarni-Manchado and Cheynier, 2006) (Figure 9). These phenolic acids are very often conjugated to other forms of organic molecules. Thus, the conjugation of the hydroxybenzoic acids to glucose or different alcohols-acids creates esters. The conjugation of caffeic acid to quinic acid gives chlorogenic acid (5-caffeoylquinic acid), the most frequently encountered caffeic acid ester. While, the conjugation of hydroxycinnamic acids to mono or di-amines leads to phenolamides (Macheix *et al.*, 2005).

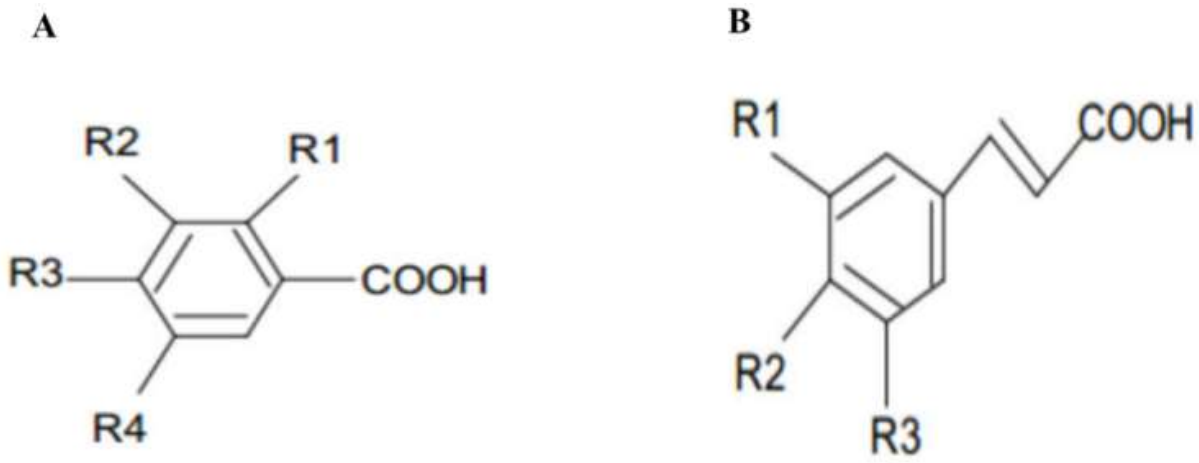



**Figure 9:** Basic structures of hydroxybenzoic acids (A) and hydrocinnamic acids (B) (Sarni-Manchado and Cheynier, 2006).

### I.7.1.2 Flavonoids

Flavonoids are characterized by their basic skeleton consisting of 15 carbon atoms arranged in a type phenyl-2-benzopyrane configuration ($C_6$-$C_3$-$C_6$) (Figure 10). According to the modifications of the heterocycle C, flavonoids are grouped into several classes including anthocyanidins, flavonols, flavones, flavanols, flavanones, chalcones, and isoflavonoids (Treutter, 2006) (Figure 11). The most common flavanols are known to be flavan-3-ols. The flavan-3-ols carry a hydroxyl group at the 3-position of the heterocycle and a single saturated bond between C-2 and C-3 carbon atoms. The flavanones carry a ketone group at the 4-position of the heterocycle and a single saturated bond between C-2 and C-3 carbon atoms. The flavanonols (dihydro flavonols) carry a hydroxyl group at 3-position and a ketone group

at 4-position of the saturated heterocycle. The flavones carry a ketone at 4-position of the heterocycle, in addition to an unsaturated bond between C-2 and C-3 carbon atoms. The flavonols carry a hydroxyl group at 3-position and a ketone group at 4-position of the saturated heterocycle, and a single saturated bond between C-2 and C-3carbon atoms. The hydroxyl groups of the flavonoids aglycones are generally substituted by the glycosyl and methoxyl groups. The hydroxyl groups the flavonoid sugar units may be substituted with glycosyl and acyl groups.

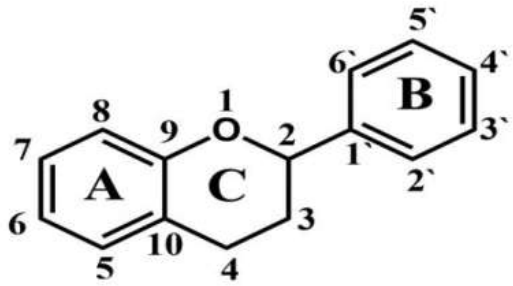



**Figure 10:** Basic structure of flavonoids (Belyagoubi, 2012).

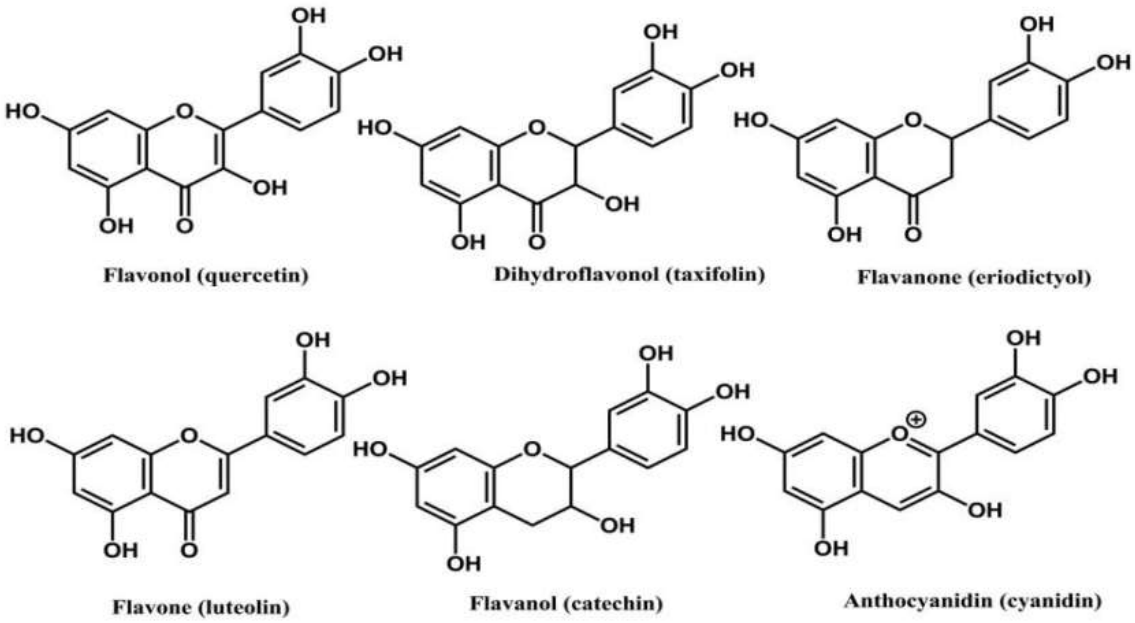



**Figure 11:** Main sub-groups of flavonoids (Erdman *et al.*, 2007).

### I.7.1.3 Lignins

Lignin is nearly exclusively based on phenylpropanoid units derived from the oxidative polymerization of hydroxycinnamoyl alcohol derivatives (monolignols) $(C_6\text{-}C_3)_n$ (Davin *et*

*al*., 2008). These monolignols are synthesized via the phenylpropanoid pathway and derive from ρ-coumaroyl-CoA by a series of reactions involving hydroxylases, Co-A ligases, methylases, reductases, and dehydrogenases. The three major monolignols namely ρ-coumarylic, coniferylic and sinapylic alcohols constitute the H (ρ-hydroxyphenyl), G (guaiacyl), and S (syringyl) units of the lignin polymers (Figure 12). The relative proportion of these monolignols varies between different groups of plant species, and tissues (Weng and Chapple, 2010). They are essential for the maintenance of plants and therefore their development, through their structural role in the cell walls.

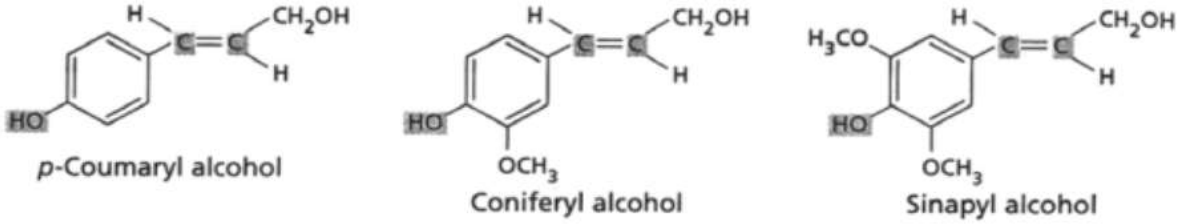



**Figure 12:** View of mains monomers constituting of lignins (Bahaz and Rachdi, 2010)

### I.7.1.4 Tannins

Hydrolyzable tannins are esters of carbohydrates and phenolic acids or their derivatives. Due to their numerous OH groups, they dissolve more or less (depending on their molecular weight) in water, forming colloidal solutions. The hydrolysable tannins are divided into the following subgroups: gallotannins, which by enzymatic hydrolysis gives more sugars and gallic acid; and ellagitannins, which by enzymatic hydrolysis gives sugars, ellagic acid, and a hexahydrophenic acid derivative (Figure 13).

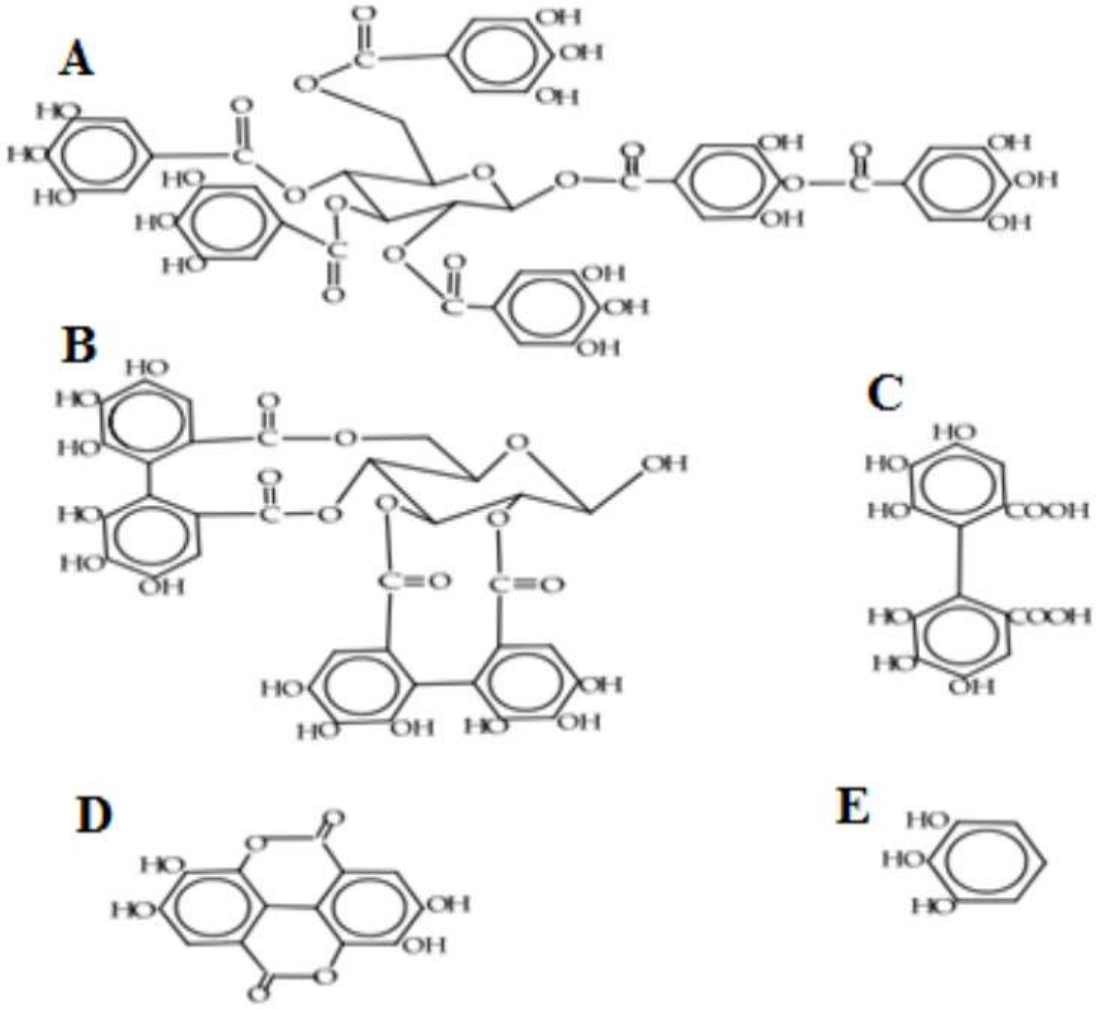



**Figure 13:** Hydrolysables tannins and some derivates (Castillo *et al*., 2012)

(A): gallotannins, (B): ellagitannins, (C): hydroxyphenolic acid, (D): ellagic acid, (E): gallic acid**.**

Condensed tannins, also called proanthocyanidins, are the polymers of flavan-3-ol (catechin) and flavan-3,4-diol (leucoanthocyanidins) (Figure 14). Their high molecular weight (1000-3000 Daltons) gives them relative immobility and their study is made difficult by their complexity and their ability to form bonds with proteins.

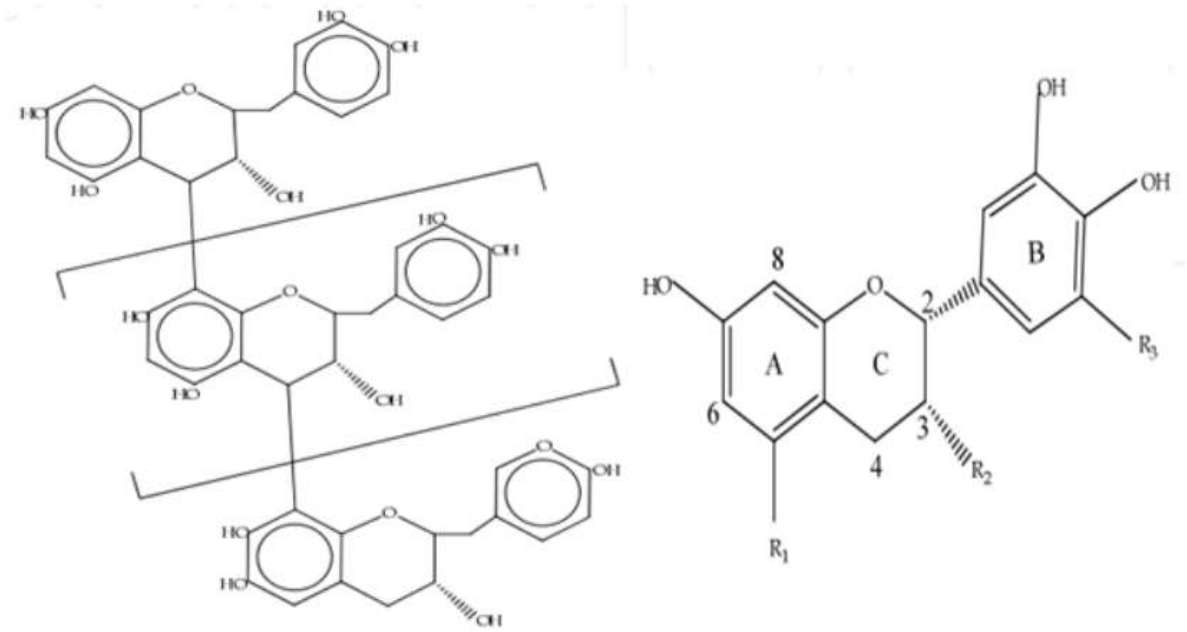



**Figure 14:** Structures of some condensed tannin classes (Castillo *et al*., 2012)

### I-7-1-5- Coumarins

Coumarins are classified as a member of the benzopyrone family. All of which consists of a benzene ring joined to a pyrone ring. During the synthesis of these compounds, orthohydroxylation should respectively take place on p-coumaric, caffeic and ferulic acid. Coumarins can be free, etherified or engaged in a heterosidic bond. Depending on the complexity of their structures, coumarins are classified into four main coumarin sub-types: the simple coumarins, furanocoumarins, pyranocoumarins, and the pyrone-substituted coumarins. The simple coumarins (e.g. coumarin, 7-hydroxycoumarin, and 6,7-dihydroxycoumarin), are hydroxylated, alkoxylated and alkylated derivatives of the parent compound, coumarin, along with their glycosides. The most common in the plant kingdom have substitutions (OH, $OCH_3$ or O-Glc) in positions 6, 7, and 8 of the nucleus benzo-α-pyrone (Figure 15A). Furocoumarins or furanocoumarins consist of a five-membered furan heterocycle attached to the nucleus benzo-α-pyrone, divided into linear form (e.g. 6,7-furocoumarin) (Figure 15B) or angular form (e.g. 7,8-furocoumarins) (Figure 15C) with substitution at one or both of the remaining benzoic positions. Many derivatives of these basic structures exist with additions of various groups (hydroxy, alkoxy, geranyloxy,) on the carbons of 2, 5 and/or 8 positions. These derivatives can be quite simple, as in the case of hydroxypsoralenes and methoxypsoralenes, or even more complex for example

athamantine or lacolumbianadine. Pyranocoumarins are analogous to the furanocoumarins, but contain a six-membered pyrane heterocycle attached to the nucleus benzo-α-pyrone either in the prolongation (linear form) or laterally (angular form) (Figure 15D). Coumarins substituted in the pyrone ring include 4-hydroxycoumarin, 3-substituent, and biscoumarins or dimeric coumarins formed by the connection of simple coumaric units (Figure 15E).

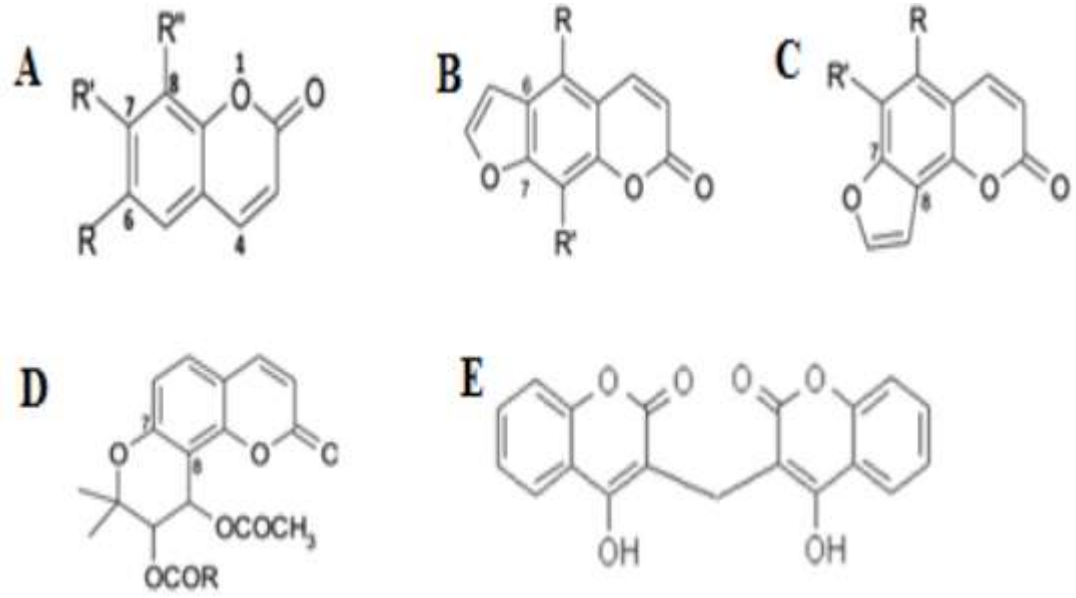



**Figure 15:** Main types of coumarins (Harkati, 2011)

### I.7.1. 6 Stilbenes

Stilbenes (1,2-diphenylethylene) are defined by their basic skeleton consisting of two phenyl nuclei connected to each other by a double ethene bridge that can exist in the *cis* (Z) or *trans* (E) form (Figure 16). They are derived from the phenylpropanoid pathway and are synthesized by stilbene synthase, a characteristic enzyme of stilbene-producing plants. The *cis*- and *trans*-stilbene simple forms can be methylated, methoxilated, hydroxilated, glycolysated, conjugated with glycosides or oligomerized into complex structures to form the diversity of stilbene compounds (Shen *et al*., 2009).

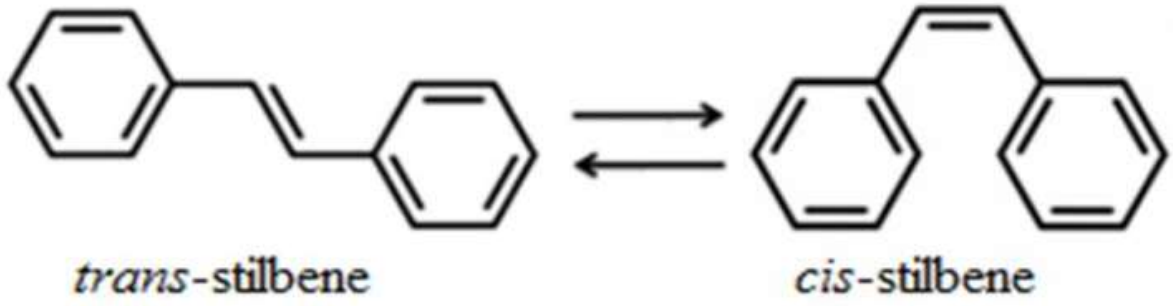



**Figure 16:** Structure of trans- and cis-stilbenes forms (Chong *et al*., 2009).

### I.7.2 Alkaloids

Alkaloids are one of the largest groups pf secondary metabolites (about 20% of secondary metabolites are classified in this group) with nearly 10,000-12,000 different structures (Stöckigt *et al*., 2002). They are natural heterocycle compounds with nitrogen as a heteroatom, with a more or less basic complex molecular structure (Zenk and Juenger, 2007). They are primarily formed from tryptophan, tyrosin, phenylalanin, lysin and arginin amino acids and catalyzed by highly stereo, regio and substrate-specific enzymes (Croteau *et al.*, 2000). Alkaloids isolated or linked to another fraction of steroid, terpenoid type. From the structural point of view and according to their precursor amino acids, there are many forms of alkaloids (Aniszewski, 2007):

- Pyrrolizidinic alkaloids, they are derived from the transformation of ornithine and possess the pyrrolizidin nucleus in common;

- Isoquinolinic and quinolizidinic alkaloids, they are formed from lysin and have the quinolizidin nucleus in common;

- Indolic alkaloids;

- Acridonic alkaloids;

- Tropanic alkaloids.

### I.7.3 Terpenoids

Terpenoids are natural hydrocarbons of cyclic or open-chain structure, widely distributed in the plant kingdom with many volatile representatives, from the mevalonic acid pathway (Bhat *et al*., 2005). They are formed by polymerization of isoprenic units with 5 carbon

atoms ($C_5H_8$). Their basic structural element: isopentenyl diphosphate and its isomer the dimethylallyl diphosphate (Bruneton, 1999), which classify them either in hemiterpens ($C_5H_8$), monoterpens ($C_{10}H_{16}$), sesquiterpens ($C_{15}H_{24}$), homoterpens ($C_5H_8$ and $C_5H_8$), diterpens ($C_{20}H_{32}$), triterpens ($C_{30}H_{48}$), and tetraterpens ($C_{40}H_{96}$) having a high vapor pressure which allows them to be vaporized in the atmosphere. Terpenoid families include hormones (gibberellins and abscissic acid), carotenoid pigments (caroten and xanthophylle), sterols (ergosterol, sitosterol, cholesterol) and its derivatives (digitalic heterosids), latex and a large part of essential oils.

## I.8 General Information on fruits and vegetables

### I.8.1 Fruits and vegetables quality and safety aspects

Quality is the combination of characteristics and properties that gives the commodity value for food and fulfills consumer's requirements (Barrett, Beaulieu, and Shewfelt, 2010). Quality focuses on the nutritional value, safety, sensory (color, taste), physical appearance (size, shape, absence of defects) and shelf life of fruits and vegetables (Barrett *et al*., 2010; Francis *et al.*, 2012). fruits and vegetables quality are determined by pre-postharvest production factors such as; location, climate, soil type, water quality, plant nutrition, use of pesticides and plant growth regulators; Postharvest handling; storage and processing (El-Ramady *et al*., 2015; Rehman, Alam, Malik, Ali, and Sarfraz, 2015). To producers quality is considered as high yield, resistance to diseases, ease to harvest, good appearance and few defects as well as good shipping quality, while marketers and distributors consider quality as good appearance, firmness and shelf life (Rouphael, Schwarz, Krumbein, and Colla, 2010; Zhang *et al*., 2014). On the other hand, consumers consider quality as good appearance, firmness, size, good flavor, convenience, nutritive value and good edible quality that defines their buying behavior (Nicolaï *et al.*, 2014; Zhang *et al*., 2014 & Armachius *et al*, 2017). Increased consumer awareness on food safety has led to public health concern on freshly consumed food like fruits and vegetables, related to food-borne illness, safe use of pesticides and ripening chemicals (Hassani *et al*., 2012; Martínez-Vaz, Fink, Diez-Gonzalez, & Sadowsky, 2014; Siroli, Patrignani, Serrazanetti, Gardini, and Lanciotti, 2015; Unnevehr, 2015). Fruits and vegetables are colonized by a range of spoilage and pathogenic microorganisms (Olaimat & Holley, 2012). They get contaminated by dust, soil, and water during harvesting, handling, processing, distribution and preparation (Gil *et al*., 2015). Consumption of contaminated fruit and vegetables and their products has been linked to disease outbreaks caused by pathogens such as, Bacillus species, Salmonella

species, klebsiella species, Escherichia coli and Listeria monocytogens (Caponigro *et al.*, 2010; Eni, Oluwawemitan, & Solomon, 2010; Martínez-Vaz *et al.*, 2014).

Safe use of pesticides and ripening chemical, detection and assessment of food adulteration are among important areas of food safety (Martínez-Vaz *et al*., 2014; Siroli *et al*., 2015). Washing and sanitizing steps before or during processing reduces the risk of chemical residues, pathogens and other contaminants on fruit and vegetables (São José *et al*., 2014). To ensure adherence to food safety Gil *et al*., (2015) recommended that, fruit and vegetables producers and all involved in the value chain should be equipped with skills and knowledge on food safety which includes; clean handling practices, personal hygiene, process hygiene and control of cross-contamination. For that reason, the differences between developed and developing countries in production, handling, processing, storage and distribution should not be an excuse to compromise fruis and vegetables quality and safety standards (Gil *et al*., 2015; Unnevehr and Ronchi, 2014).

### I.8.2 Influence of pesticides application on fruits and vegetable safety

Pesticides are intended to control pest and diseases that could cause losses of the crop, however, their misuse can lead to adverse effect to human health and environment (Damalas *et al.*, 2011). High application rates, wrong timing, and unfavorable environment are among other factors reported to associate with; toxic effect to plants and non-target organisms, water contamination and air pollution (Damalas *et al*., 2011). de Bon *et al*., (2014) reported that, pesticides misuse is due to lack of skills and knowledge on application practices, disposal, dosage and the knowledge about pests and diseases. Although pesticides application level on food crops are reported to be low in Africa, the level of application on fruits and vegetables is exceptionally high (de Bon *et al*., 2014). Subsistence FV farmers in SSA have been reported to rely more on pesticides use than on other pest control methods (Karungi, Kyamanywa, Adipala, and Erbaugh, 2011). Studies in Tanzania, Kenya, Uganda, Ethiopia, Cameroon, Benin and Ghana reported pesticides malpractice, whereby; tomatoes are mostly sprayed with pesticides (de Bon *et al*., 2014; Karungi *et al*., 2011; Tilahun *et al*., 2014). Safety implications on use of pesticides include vomiting, headache, skin irritation, respiratory diseases, poisoning and cancer to human (McCormack *et al*., 2012). Acute poisoning remains a severe problem for human health in SSA (de Bon *et al*., 2014). Therefore, pesticides application threatens fruit and vegetables safety in SSA.

### I.8.3 Influence of bio-chemical alternatives to control pest on fruits and vegetable safety

Bio-chemical pesticides are bio-pesticides or non-chemical that occur naturally and control pests by non-toxic mechanisms (Dutta, 2015; Villaverde, Sevilla-Morán, Sandín-España, López-Goti, and AlonsoPrados, 2014). Bio-pesticides can be living organisms or their products or by products used to control plant pests (Czaja *et al*., 2015). These include bio-fungicides (Trichoderma), bio-herbicides (Phytopthora) and bio-insecticides (Bacillus thuringiensis-Bt) (Czaja *et al*., 2015). Bio-pesticides are excellent alternative to chemical pesticides, as they are specific to pest, low non-target organism toxicity, decompose quickly, less harmful and pose less effect to the environment (Seiber, Coats, Duke, and Gross, 2014). Plant extracts and oil from neem (*Azadiractha indica*), tobacco (*Calotropis procera*), garlic (*Allium sativum*), and dried chilies are used to control and repel some insect pests in Asian and African countries (Eze and Echezona, 2012; Khater, 2012). Problems associated with use of chemical pesticides like environmental pollution, reduction of beneficial species not targeted, persistent toxicity in the food chain and health related problems to humans like cancer makes non-chemical pesticides preferable (Dutta, 2015; Sarwar, 2015). Due to their specificity and low risks, bio-pesticides are essential tool to control plant growth, fruit qualities, postharvest losses of fruit and vegetables. (Armachius *et al***.,** 2017)

### I.8.4 Nutritional quality of vegetable and fruits

Heart disease, stroke, cancer and diabetes, which are chronic diseases, are a leading cause of mortality worldwide. Excess weight and outright obesity are a growing concern. Prevention of these problems is linked to lifestyle choices (Ariel R. Vincente *et al*., 2014). There might be an evolutionary discordance between modern diets, rich in calories from fats and starches and low in fruits and vegetables, and human nutritional requirements (Martin *et al*., 2013). Consequently replacing some added sugars and saturated fat with more fruits and vegetables may benefit health. Researches indicate that fruit and vegetable consumption reduces the risk of major diseases and possibly delays the onset of age-related disorders.

The dietary constituents obtained from fruits and vegetables include water, fiber, proteins (more abundant in legumes), sometimes fats (olive, avocado, nuts), organic acids and digestible carbohydrates. Starch-based staples (potato, cassava, corn, banana, plantain) provide a major energy source in some regions. Fruits and vegetables provide minerals and vitamins. They are the main dietary source of vitamin C and a significant source of pro-vitamin A and vitamin B6. Compared to other food sources, they are high in potassium and low in sodium. Ascorbic acid

in fruits and vegetables may enhance the bio-availability of dietary iron. Fruits and vegetables provide unique and appealing textures, colors and flavor, they are relatively low in calories (excluding staple crops) and are cholesterol-free. They also include a variety of non-nutritive bioactive phytochemicals with health benefits (Ariel R. Vincente *et al*., 2014). Some constituents of horticultural crops that help to prevent disease include fiber, phytosterols, carotenoids such as lycopene, ascorbic acid, tocopherols, glucosinolates, thiosulfinates and phenolics such as flavonoids, hydroxycinnamic acid-derivatives, stilbenes and catechins (Voutilainen *et al.,* 2006; Ignarro *et al*., 2007; Holst and Williamson, 2008; Chen and Chen, 2013). Fruit phytochemicals and diet constituents may exert antagonistic, additive or synergistic effects (Heinonen *et al*., 1998). Although the mechanisms by which fruits and vegetables promote human health are unclear, current evidence has led to recommendations that healthful diets include a variety of fresh or processed horticultural commodities. In spite of these guidelines, fruit and vegetable intake is often below the dietary goal of five to 10 servings or 400 g of fruits and vegetables daily (Vincente *et al* ., 2014).

### I.8.5 Some nutrient components of fruits and vegetable

#### I.8.5.1 Water

60% of the body's weight is comprised with water and is essential for good health. An intake of 2.2 or 3.0 l of total beverages a day is recommended for men and women. Individual needs depend on environmental conditions, diet and physical activity. Water is also the most abundant single component of fresh fruits and vegetables and in leafy vegetables it may be up to 95% of the mass. The percentage of water varies among individual fruits and vegetables due to structural differences and the developmental stage (Ariel R. Vincente *et al* ., 2014).

#### I.8.5.2 Proteins and nitrogen compounds

1% of the fresh mass of most fruit and vegetable tissues is represented by proteins. Legumes may contain 15 to 30% protein. Vegetables and legumes account for 6.0% of protein intake, while fruits only contribute 1% (Hiza and Bente, 2007). Some plant seeds, particularly legumes, contain some anti-nutritional proteins (Lajolo and Genovese, 2002).

A number of non-protein nitrogenous compounds including free amino acids, chlorophylls, polyamines or alkaloids are also present in fruits and vegetables.

### I.8.5.3 Lipids and fatty acids

Lipids may be used as energy sources and are the main components of cellular membranes and waxes. They are mainly present as triglycerides (esters of glycerol and three fatty acids). However, diverse chemical forms co-exist within this group. Phospholipids, in which one fatty acid is replaced by phosphoric acid, are also important membrane constituents. The fat concentration varies with the commodity, but most fruits and vegetables have ,1% lipid, with avocadoes, olives and nuts being the exceptions (Vincente *et al* ., 2014).

The physical and chemical properties of lipids are largely determined by their constituent fatty acids. Fatty acids in foods are usually aliphatic and monocarboxylic. They may be saturated or unsaturated to varying degrees and may contain from four to 26 carbons. Oleic (18:1) and linoleic (18:2) acids are the most prevalent (Ariel R. Vincente *et al* ., 2014). Olive oil and other fats high in monounsaturated fatty acids can help lower low-density lipoprotein (LDL)-cholesterol (so-called "bad" cholesterol), while protecting highdensity lipoprotein (HDL)-cholesterol ("good" cholesterol) when consumed in moderation in place of saturated fats. Fats derived from animal sources (e.g., butter, cream, hard cheeses) have a high proportion of saturated fats, while oils from plant sources such as olive and canola have the lowest. Fatty acids are required for human body functions as they are used to produce lipids and hormone-like substances that regulate blood pressure, blood clotting and immune and inflammatory responses. The human body can produce most fatty acids except linoleic acid and α-linolenic acids, which are common in plant oils (Vincente *et al* ., 2014).

Plant-derived foods do not contain significant amounts of cholesterol but do contain cholesterol-like steroids or phytosterols. These are present at highest concentrations in vegetable oils but may occur at appreciable levels in some horticultural crops (Ariel R. Vincente *et al* ., 2014). Fat-rich fruits and nuts, cauliflower, broccoli and carrots are good sources of phytosterols. They are absorbed only in trace amounts but inhibit the absorption of intestinal cholesterol (Jenkins *et al.,* 2001). Clinical trials indicated that a daily intake of 0.8 g significantly reduced LDL and total cholesterol in the blood (Moruisi *et al.,* 2006). Natural dietary intake varies from 167 to 437 mg per day (Ostlund, 2002). However, in vegetarian diets it may be as high as 1 g per day.

### I.8.5.4 Digestible carbohydrates

Carbohydrates are the most abundant constituents in fruits and vegetables after water, accounting for 50-80% of dry weight. Carbohydrate functions include storage of energy

reserves and they make up much of the structural framework of cells. Carbohydrates and proteins yield 4 kcal/g, while fats yield 9 kcal/g (Ariel R. Vincente *et al*., 2014). Glucose and fructose are the most common simple sugars in fruits and the disaccharide sucrose, the primary transport form of carbohydrate in most plants, yields glucose and fructose upon hydrolysis. Glucose, fructose and sucrose are water-soluble and together are primarily responsible for the sweet taste of fruits and vegetables. In many fruits, glucose and fructose are more abundant than sucrose, but in vegetables the sucrose concentration is higher (Ariel R. Vincente *et al*., 2014). Other mono- and disaccharide sugars such as xylose, arabinose, mannose, galactose and maltose may also be present in small amounts (Salunkhe *et al*., 1991). Total carbohydrate also includes starches, which are organized into small grains within chloroplasts or in specialized plastids, called amyloplasts. (Ariel R. Vincente *et al*., 2014).

### I.8.5.5 Dietary fiber

Fibers are non-digestible carbohydrates and lignin in plants (Institute of Medicine, 2001). Dietary fiber includes very diverse macromolecules exhibiting a variety of physical-chemical properties. The main components of fiber are cellulose, cross-linking glycans (CGL), pectins, lignin, resistant starch and non-digestible oligosaccharides.

#### I.8.5.5.1 Benefits of fiber intake

One of the best-known benefits of dietary fiber is its modulation of the intestinal function (Institute of Medicine, 2001). Fiber-rich meals promote satiety earlier, usually have fewer calories and can assist weight control (Marlett *et al*., 2002). Undigested dietary fiber is fermented in the colon to form acetic, propionic and butyric acids which participate in satiety signaling (Martin *et al*., 2013). High fiber intake is associated with disease prevention (Meyer *et al*., 2000; Institute of Medicine, 2001), reduced serum cholesterol and blood pressure and lower risk of coronary disease (Rimm *et al*., 1996; Wolk *et al*., 1999). Increasing viscous fruit

and vegetable fiber and whole grains improves glycemic control and bodyweight management (Martin *et al*., 2011). Total fruit and vegetable consumption was inversely associated with colorectal cancer risk (Terry *et al*., 2001). Fiber may reduce the bioavailability of some phytochemicals or may be reduced by binding or entrapment (Palafox-Carlos *et al*., 2011). National dietary guidelines recommend increasing dietary fiber intake to 20-35 g per day (Ariel R. Vincente *et al* ., 2014). Fiber properties differ greatly depending on the food source.

### I.8.5.6 Calcium (Ca)

Calcium plays an important role in structure and function of bones and it regulates intracellular events in body tissues and plays an important role in muscle contraction, enzyme activities, nerve functions, blood clotting and regulation of homeostasis among other functions (Callistus *et al.,* 2017). Insufficient Ca in the diet has been linked to osteoporosis and bone fractures in adults (Whiting, 2010), softening and deformation of the bones (rachitis) in children normally under two years of age (Adámková, 2014) as well as ageing and cardiovascular diseases (Beto,2015; Callistus *et al*., 2017).

### I.8.5.7 Magnesium (Mg)

Magnesium is vital in human nutrition due to its function as a cofactor for more than 300 essential enzyme systems, its requirement for increased DNA and RNA synthesis, energy generation as well as glycolysis and has also been shown to be essential for mitochondria to carry out oxidative phosphorylation (Food and Nutrition Board, 1997). Mg deficiency has also been associated with insulin resistance and vascular disease (Nadler *et al*., 1993). Evidence suggests that the majority of Mg deficiency diseases are due to non-consumption of fresh, green vegetables. (Callistus *et al*., 2017).

### I.8.5.8 Vitamin C

Ascorbic acid (AsA) (Figure 17) and its first oxidation product dehydroascorbic acid, which is reduced in the human body, are both considered to be vitamin C. AsA is a water soluble, carbohydrate-derived compound with antioxidant and acidic properties due to a 2,3-enediol. Humans and a few other species cannot synthesize AsA (Chatterjee, 1973) because the gene coding for the last enzyme in the pathway (L-gulono-1,4-lactone oxidase) is not functional (Valpuesta and Botella, 2004). Plants synthesize AsA via a pathway that uses L-galactose as a precursor (Smirnoff and Wheeler, 2000; Smirnoff, 2000). Another pathway using galacturonic acid recycled from cell wall pectin degradation is present in plants (Agius *et al*., 2003). AsA is involved in collagen biosynthesis (Murad *et al*., 1981). It is generally recognized that dietary AsA has important health benefits (Hancock and Viola, 2005). In meat poor diets, dietary AsA can improve iron uptake (Frossard *et al.,* 2000). The recommended dietary allowance of vitamin C is 75 and 90 mg per day for men and young women, respectively (Levine *et al*., 2001). Fruits, vegetables and juices are the main dietary sources of vitamin C. Fruits and vegetables account for 90% of the vitamin C (Hiza and Bente, 2007). Vitamin C concentration varies depending

on the commodity (Noctor and Foyer, 1998), from 1 to 150 mg/100 g FW (Lee and Kader, 2000).

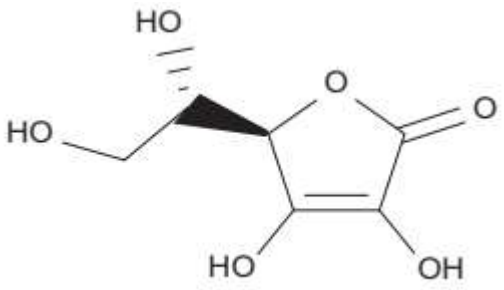



**Figure 17:** Structure of ascorbic acid, a main antioxidant present in fruits and vegetables.

Wide variations in vitamin C concentrations may exist among cultivars or species of the same genus: in one study, AsA in Actinidia species varied from 29 to 80 mg/100 g FW (Nishiyama *et al.*, 2004). For any given product, AsA concentrations may vary due to genetic and environmental factors (reviewed in Lee and Kader, 2000). Sunlight exposure is a main factor that determines the AsA concentration. In general, more sunlight received during growth increases ascorbic acid. Retention of AsA is also affected by storage and processing conditions. Potatoes lose up to 80% of their original AsA over nine months' storage. AsA stability is reduced at high temperatures and bruising increases AsA degradation. Ascorbic acid is highly susceptible to oxidation, either directly or through the enzyme ascorbate oxidase (Sanmartin *et al*., 2007). The first oxidation product of AsA, dehydroascorbic acid, still has vitamin C activity, but this is lost on further oxidation (Salunkhe *et al*., 1991). When vegetables are cooked, high losses of vitamin C are expected. Losses can be reduced by steam cooking. Freezing reduces vitamin C content slightly, but during long-term frozen storage (12 months), significant losses may occur (33-55%) (de Ancos *et al*., 2000).

### I.8.5.9 Minerals

Minerals in food items are defined as the total ash content. Minerals are usually classified as macronutrients or micronutrients, based on the relative concentrations of each nutrient considered adequate for normal tissue function (Ariel R. Vincente *et al*., 2014). Macronutrients include potassium (K), calcium (Ca), magnesium (Mg), nitrogen (N) and phosphorus (P), and their concentrations in plant tissues range from 1000 to 15,000 µg/g dry weight. Micronutrient

concentrations are 100 to 10,000-fold less than those of macronutrients. Mineral micronutrients considered essential for human nutrition include manganese (Mn), copper (Cu), iron (Fe), zinc (Zn), cobalt (Co), sodium (Na), chlorine (Cl), iodine (I), fluorine (F), sulfur (S) and selenium (Se). Macronutrients can also be classified into those that maintain their identity as ions within plant tissues (e.g., K1, Ca21 and Mg21) and those that are assimilated into organic compounds (e.g., N, P and S). In general, vegetables are a richer source of minerals than fruits (Ariel R. Vincente *et al* ., 2014). Minerals have both direct and indirect effects on human health. The direct effects of minerals are the consequences of their consumption by humans, while indirect effects are their impact on fruit and vegetable quality and subsequent consumer acceptance. From a direct nutrition standpoint, potassium is the most abundant in both fruits and vegetables, but nitrogen and calcium have major impacts on food quality. Until recently, nutrition research focused on single-mineral effects on human health, generally with incongruent results (Aaron and Sanders, 2013).

The recognition that minerals are not consumed individually but as combined constituents of a varied diet has shifted efforts to unraveling the role of overall diet, or dietary patterns, in blood pressure, cardiovascular diseases, bone diseases and other chronic disorders. Epidemiological surveys suggest that total diet has more influence on health than specific components (Ariel R. Vincente *et al* ., 2014). It is increasingly clear that it is not only an excess or deficiency of a single mineral but also of multiple nutrients in combination that have dietary effects on health.

Fruits and vegetables are not recognized as primary sources of mineral nutrition (Fairweather-Tait and Hurrell, 1996). Nevertheless, the Dietary Approaches to Stop Hypertension (DASH) emphasize fruits, vegetables and low-fat dairy products as a source of minerals. In the DASH dietary pattern, vegetables contribute 14.3, 15.5, 16.2 and 10.4% of required calcium, magnesium, potassium and zinc, respectively (Lin *et al.*, 2003). There has been a trend towards lower mineral contents in fruits and vegetables over the past decades (Ekholm *et al*., 2007) which has not been fully offset by increased fruit and vegetable consumption. Strategies for improving our mineral intake from fruits and vegetables have been implemented. These comprise increasing the consumption of fruits and vegetables and increasing concentrations of essential nutrients through fortification. Alternative approaches include improving nutrient bioavailability and retention (Ariel R. Vincente *et al*., 2014).

### I.8.6 Antioxidants

Reactive oxygen species (ROS) are partially reduced forms of oxygen such as singlet oxygen, hydrogen peroxide ($H_2O_2$), superoxide ($O_2^-$) or hydroxyl radical ($OH_2^{-\bullet}$) ( Mittler, 2002). ROS cause deleterious modifications in proteins, lipids and nucleic acids by altering normal metabolism in living organisms (Waris and Ahsan, 2006;). The protective effects of fruit and vegetables are attributed in part to the presence of antioxidants (Cao *et al*., 1996; Wang *et al*., 1996). Antioxidants are compounds that prevent uncontrolled cellular oxidation (Dragsted, 2003). They are present in all plant organs.

#### I.8.6.1 Ascorbic acid (AsA)

Ascorbic acid is one of the most important compounds for human nutrition present in fruits and vegetables (Larson, 1988). Besides its vitamin functions, the role of AsA in disease prevention is associated with its capacity to neutralize ROS (Ariel R. Vincente *et al*., 2014).

#### I.8.6.2 Phenolic compounds

Phenolics are diverse compounds derived from aromatic amino acids. Their distinctive feature is the presence of aromatic rings with variable degrees of hydroxylation (Mattila *et al*., 2006). They contribute to fruit pigmentation and act as predator deterrents and antimicrobials. Phenolic compounds contribute to astringency and impart bitter taste in some products. They may also protect plant tissues against excessive UV radiation. They can be oxidized by plant peroxidases (PODs) and polyphenol oxidases (PPOs), leading to undesirable tissue browning. They are generally present at low concentrations, but in blueberries, levels can be over 0.1%. Phenolics accumulate preferentially in the peel, but this varies depending on species and chemical group. Eggplant anthocyanins are concentrated in the peel, while chlorogenic acid, the main antioxidant, predominates in the pulp, surrounding the seeds. As with other compounds, the health-promoting effects of phenolics depend on their bioavailability (Duthie *et al*., 2003; Seeram *et al.,* 2006; Konic Ristic *et al*., 2011), but paradoxically their concentration in plasma is usually very low (Manach *et al.,* 2005). Many phenolic compounds have been identified in plants (Tsao and Deng, 2004). They are grouped into sub-classes such as phenolic acids, flavonoids, lignans, stilbenes, tannins, coumarins and lignin.

### I.8.6.3 Flavonoids

Flavonoids are a large group of phenolic compounds with two aromatic rings associated by a 3 C oxygenated heterocycle. They are usually present as glycosides, which are more soluble than the corresponding aglycons, and are compartmentalized into the vacuoles (Rice-Evans *et al.*, 1997). There are different flavonoid sub-classes: flavones and flavonols, flavanones and flavanols, isoflavones, proanthocyanidins and anthocyanidins (Le Marchand, 2002). However, pepper fruit are particularly rich in flavonoids, a large class of compounds ubiquitous in plants, that exhibit antioxidant activity, depending on the number and location of hydroxyl groups present (Rice-Evans *et al.*,1996). In addition to antioxidant function, flavonoids are reported to possess numerous biological, pharmacological, and medicinal properties, including vasodilatory, anticarcinogenic, immune-stimulating, antiallergenic, antiviral, and estrogenic effects, as well as inhibition of various enzymes involved in carcinogenesis. (Hollman *et al.*,1996).

### I.8.7 Fruits and vegetables: disease prevention

Epidemiological studies indicate that antioxidants present in fruits and vegetables, including vitamins C and E, may be important in prevention of numerous degenerative conditions, including different kinds of cancer, cardiovascular disease, stroke, atherosclerosis, and cataracts (Block *et al.*,19948 and Van Poppel *et al.*, 1997). Oxidative damage catalyzed by reactive oxygen species (ROS) has been implicated in over 100 degenerative conditions (Jacob., 1995). ROS cause damage to cellular membranes, proteins, and DNA, which increases the susceptibility of cells to chronic diseases. Oxidative damage in the body is exacerbated when the balance of ROS exceeds the amount of endogenous antioxidants. The human body has several enzymatic and non-enzymatic defense systems to regulate ROS in vivo, but these defense mechanisms are thought to deteriorate with aging. Consumption of fruits and vegetables that are rich in antioxidant nutrients may afford additional protection against ROS-mediated disorders. Scientists have recently recognized that fruits and vegetables are not only a good source of antioxidant vitamins but also an excellent source of other essential dietary phytochemicals that can retard the risk of degenerative diseases (Hasler *et al.*,1998). The potential health effects of phytochemicals are associated with numerous mechanisms, including prevention of oxidant formation, scavenging of activated oxidants, reduction of reactive intermediates, induction of repair systems, and promotion of apoptosis (German *et al*., 1998).

Of interest is how and why fruits and vegetables generate nutraceutical compounds and for what purpose. With regard to peppers, the presence of different antioxidative enzymes and their corresponding metabolites in pepper peroxisomes implies that these organelles might be an important pool of antioxidants in fruit cells, where these enzymes could also act as modulators of signal molecules ($O_2^-$, $H_2O_2$) during fruit maturation (Mateos *et al.*, 2003). In one study of the peroxisomal fractions of green and red pepper fruits (Capsicum annuum L., type Lamuyo), the quantity and activity of antioxidant enzyme systems was generally higher in green than in red fruits (Mateos *et al*., 2003).

**I.8.8 Mechanisms of some compounds by which consumption of vegetables and fruit may protect against cancer.**

Vitamin C

Vitamin C is present in the greatest amounts in fruits and vegetables, including citrus fruits and juices, broccoli, green peppers, tomatoes, strawberries, melons, cabbage, and leafy green vegetables. Vitamin C is labile to heat and oxidation and, because it is a water soluble vitamin, can also be lost in cooking. Supplements and fortified foods can provide substantial amounts of this vitamin (Kristi *et al.,* 1991). The active forms of vitamin C in the body are L-ascorbic acid (the reduced form) and dehydroascorbic acid (the oxidized form). One mechanism by which vitamin C may prevent cancer, especially in the stomach, is through its ability to scavenge and reduce nitrite, thus reducing the substrate for the reaction with secondary amines to form nitros amines.~°Furthermore, ascorbate is an antioxidant and plays a role in the immune system. Other functions of vitamin C include a role in the hydroxylation of lysine and proline in the synthesis of connective tissue proteins, such as collagen; a deficiency of vitamin C may therefore affect the integrity of intercellular matrices and thus have a permissive effect on tumor growth or inhibit tumor encapsulation (Kristi *et al.*, 1991)..

Ascorbic acid has been shown in vitro to reduce the mutagenicity of gastric juice, as determined by the Ames test.43In other in vitro studies, vitamin C has been shown to cause regression of tobacco-induced malignant changes in hamster lung cells and to increase survival of ovarian tumor cells exposed to radiation in tissue culture (see Willett 38 for references). Animal experiments involving the feeding of vitamin C to animals to which carcinogens have been administered have shown mainly a protective effect or no evidence of effect. Some studies have shown that ascorbate salts, such as sodium ascorbate, promote induced bladder cancer in rats. (See National Research Councill° for references for animal studies.) Two studies in guinea pigs,

who are like humans in their requirement for exogenous ascorbic acid, showed either no effect or an enhancing effect of ascorbic acid on induced sarcomas. Ecologic epidemiologic data are consistent with lower risk of esophageal and stomach cancers in association with higher vitamin C intake (Kristi *et al.*, 1991).

**Vitamin E**

The most active form of vitamin E in foods is α-tocopherol; other tocopherols and tocotrienols also exhibit vitamin E activity. A major function of vitamin E involves its role as an intracellular antioxidant. Vitamin E protects polyunsaturated fatty acids in cell membranes from oxidarive damage. Another possible mechanism for vitamin E relates to its capacity to keep selenium in the reduced state. Vitamin E, furthermore, has been shown to inhibit the formation of nitrosamines, especially at low pH (Hu *et al.*, 1991). Vitamin E has been characterized as a cancer inhibitor that exerts its effectby preventing the formation of carcinogens from precursor compounds (Kristi *et al.*, 1991).

**Dietary fiber**

Large amounts of work have been done in the area of dietary fiber, especially in relation to colorectal cancer. Recently the US Expert Panel on Dietary Fiber defined dietary fiber as "the exogenous components of plant materials in the diet that are resistant to digestion by enzymes produced by humans. Thus, dietary fiber consists of non starch polysaccharides, including cellulose, hemicelluloses, pectin, gums, and mucilages, and nonpolysaccharides, such as lignin. (Kristi *et al.*, 1991). Epidemiologic studies suggest that adequate fiber intake consistently lowers the risk of Cardiovascular disease (CVD) and coronary heart disease (CHD), primarily through a reduction in low density lipoprotein (LDL) levels. fiber may play a beneficial role in reducing C-reactive protein levels, apolipoprotein levels, and blood pressure, all of which are biomarkers for heart disease. Regularly consuming the recommended amount of fiber has the potential to attenuate glucose absorption rate, prevent weight gain, and increase the load of beneficial nutrients and antioxidants in the diet, all of which may help prevent diabetes. ( Slavin *et al*., 2013).

Immune Function and Inflammation

Some fibers may also play a role in improving immune function via production of Short Chain Fatty Acids (SCFAs). In animal studies, addition of SCFAs to parenteral feeding increases T helper cells, macrophages, and neutrophils, and increased cytotoxic activity of natural killer

cells. There is also some evidence of increased resistance to illness or infection with fiber intake (Saavedra *et al*., 2002). Certain fibers, such as β-glucans, have been shown to interact with immune cells, and can therefore stimulate the immune system directly. Soluble, non-viscous fiber may also be potentially useful in alleviating symptoms of inflammatory conditions, such as irritable bowel syndrome (IBS), ( Slavin *et al.,* 2013 and Parisi *et al.,* 2002 ). Higher fiber intakes have been linked with lower mortality, particularly from circulatory, digestive and non-CVD/non-cancer inflammatory diseases (Chuang *et al.,* 2012). ( Slavin *et al.,* 2013)

**Polyphenols**

Polyphenols are an abundant and diverse group of secondary plant metabolites which are present in a wide variety of dietary foods and traditional plant medicines. They naturally exist in plants and plant products, including fruits, vegetables. There are currently over 8,000 phenolic structures known, of which more than 4,000 belong to the flavonoid class, and several hundred are present in edible vegetables. (Min-Ho Oak *et al.,* 2018). The structure of 4 polyphenols is characterized by at least a simple phenol core bearing at least one hydroxyl group. More than 8000 polyphenolic structures are described and they are classified according to the arrangement of the carbon atoms and their substituents in two main classes: flavonoids and non-flavonoids ( Min-Ho Oak *et al.,* 2018).

.**Flavonoids**

Flavonoids such as quercetin, kaempferol, myricetin, and chrysin are found in most fruits and vegetables. Quercetin is found in high concentrations, and is distributed widely in plant foods. Generally, fruits contain greater amounts of quercetin than vegetables and the richest sources are the outer layers of fruits and vegetables.( Kristi *et al.,* 1991) The structure of flavonoids includes two benzene rings linked via a heterocyclic pyrane ring. Most flavonoids occur in nature as glycosylated compounds. Flavonoids have antioxidant properties depending on the degree of hydroxylation of the benzene rings. This property may explain an anticarcinogenic effect. In addition, some flavonoids induce mixed-function oxidase activity, whereas others inhibit it. Flavonoids can interfere with ≥3 different free radical–producing systems, which are described below, but they can also increase the function of the endogenous antioxidants.

Flavonoids can prevent injury caused by free radicals in various ways. One way is the direct scavenging of free radicals. Flavonoids are oxidized by radicals, resulting in a more stable, less-reactive radical. In other words, flavonoids stabilize the reactive oxygen species by reacting

with the reactive compound of the radical. Because of the high reactivity of the hydroxyl group of the flavonoids, radicals are made inactive, according to the following equation (Robert *et al*., 2001)

Flavonoid(OH) + R• > flavonoid(O•) + RH

where R• is a free radical and O• is an oxygen free radical. Selected flavonoids can directly scavenge superoxides, whereas other flavonoids can scavenge the highly reactive oxygen derived radical called peroxynitrite. By scavenging radicals, flavonoids can inhibit LDL oxidation in vitro (Korkina *et al.,* 1997). This action protects the LDL particles and, theoretically, flavonoids may have preventive action against atherosclerosis. (Robert *et al*., 2001).

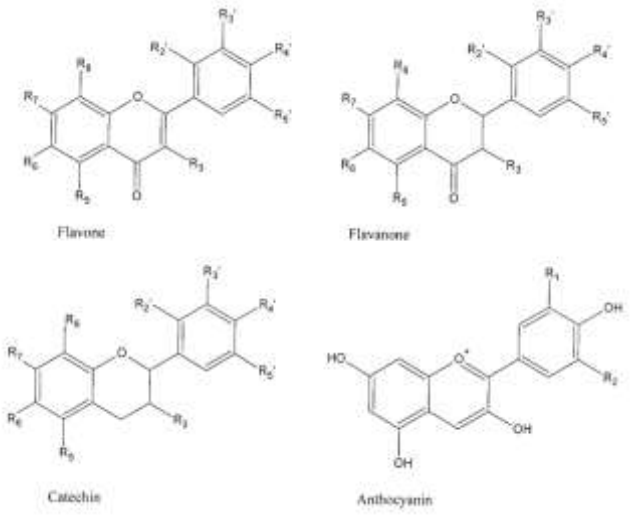



**Figure 18**: The molecular structure of each group of flavonoids.

### I.8.9 Significance of fruits and vegetables in malnutrition: the case of cancer

If the right food is not consumed in right amounts by a person it results in malnutrition, which may cause cancer. Hence, malnutrition is responsible for the development of "malnutrition cancer" as a consequence of which a huge mortality occurs every year in human beings, especially in children all over the world. If malnutrition results in cancer, it is very difficult to treat, but some improvements can be brought about by taking proper foods or nutrients and drugs (Pandey and Madhuri, 2010).

It has been elucidated that many plant products exhibit potent anticancer activity against several cancer cell lines (Madhuri and Pandey, 2008; Polidori, 2003). Fruits and vegetables play an important role for the treatment and prevention of cancer. Consumption of large amount of fruits and vegetables can prevent the development of cancer. Many doctors recommend that people wishing to reduce their risk of cancer eat several pieces of fruits and several portions of vegetables every day. An inverse relationship has been suggested between the consumption of fruits and vegetables and the incidence of cancer in multiple organs including lung, larynx, mouth, pharynx, gastrointestinal tract and pancreas (Vecchia and Tawani, 1998). The intake of 400-600 g per day of vegetables and fruits can reduce the occurrence of many common forms of cancer and diets rich in plant foods can also lower the risk of heart disease and many chronic diseases (Heber, 2004).

A report (Craig, 2006) of the WHO study on diet, nutrition and prevention of chronic diseases recommended that we daily consume at least 400 g of vegetables and fruits including at least 30 g of pulses, nuts and seeds. People who eat much quantity of vegetables have about one-half the risk of cancer and less mortality from cancer (Govind Pandey and S. Madhuri, 2010).

Epidemiological data as well in vitro studies strongly suggest that fruits and vegetables have strong protective effect against major diseases including cancer.(Govind Pandey and S. Madhuri, 2010). The protective action of fruits and vegetables against cancer has been attributed to the presence of antioxidants, especially antioxidant vitamins (Madhuri, 2008). Fruits and vegetables contain several phytochemicals which possess strong antioxidant activities. Thus, the fruits and vegetables prevent from cancer and other diseases by protecting cells from damage caused by 'free radicals'- highly reactive oxygen compounds. Certain phytochemical antioxidants with anticancer activity include vitamins (A, C, E, K), carotenoids, terpenoids, polyphenols (ellagic acid, gallic acid, tannins), flavonoids (quercetin, anthocyanins, catechins, flavones, flavonones, isoflavones), enzymes (superoxide dismutase, catalase, glutathion peroxidase), minerals (Cu, Mn, Se, Zn), polysaccharides, saponins, lignins and xanthones (Gupta and Sharma, 2006; Madhuri, 2008; Madhuri and Pandey, 2009 ; 2010; Pandey and Madhuri, 2008; Ray and Hussan, 2002).

Fruits and vegetables contain compounds such as sulphoraphane that induces GSH transferase, there by helping detoxifying many types of carcinogens. Increased consumption of vegetables can increase the plasma antioxidant capacity and is associated with the lower risk of cancer (Rao *et al.*, 2004). The vegetables and fruits are most effective against those cancers that involve

epithelial cells such as cancers of lung, esophagus, stomach, colon, pancreas and cervix ( Pandey and Madhuri, 2010).

There are many fruits and vegetable pigments such as flavonoids, carotenoids and anthocyanins which protect us from various diseases. Quercetin (a flavonoid) possesses both anticarcinogenic activity. The carotenoids are powerful antioxidants that provide protection against oxidative damage and stimulate immune function. Persons with high levels of serum carotenoids have a reduced risk of cancer. In addition, a variety of phenolic compounds (caffeic, ellagic and ferulic acids, sesamol and vanillin) are present in fruits and vegetable.

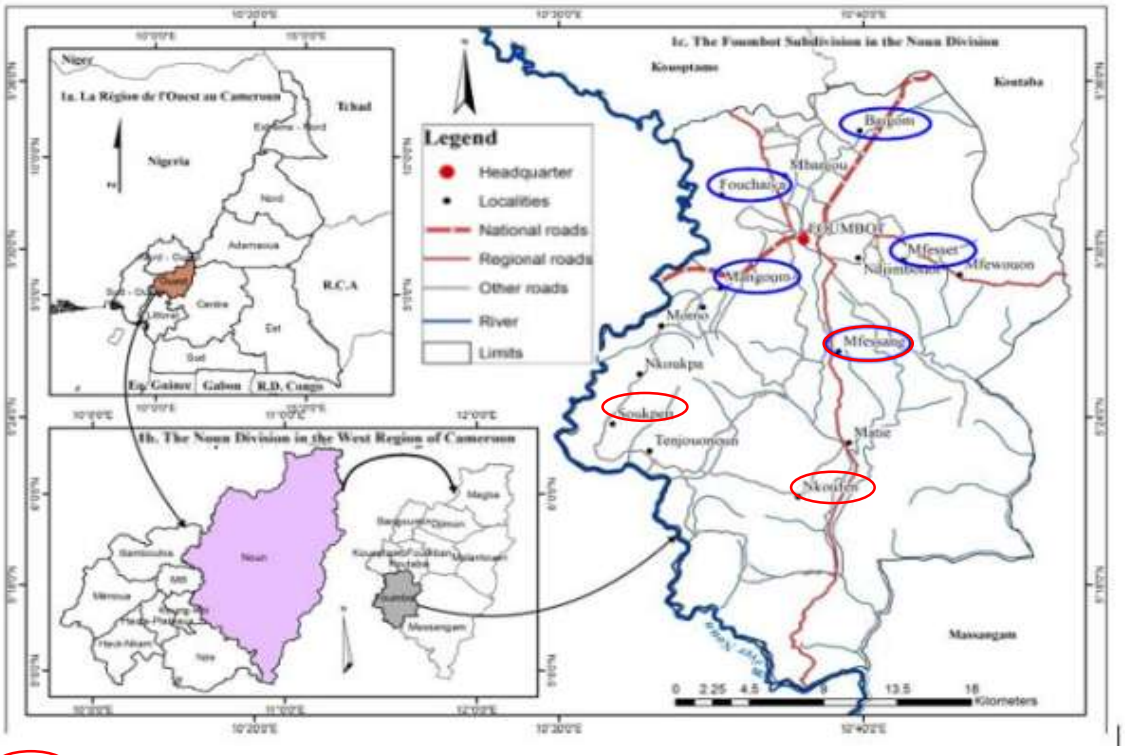
# CHAPTER II: MATERIALS AND METHODS

# CHAPTER II: MATERIALS AND METHODS

## II.1 Evaluation of the cultural practices and diseases management survey of sweet pepper at the locality of Foumbot, west region of Cameroon

### II.1.1 Study site

Foumbot is a sub-division situated in the Division of the West Region of Cameroon located 25 km from the regional capital of Bafoussam and 48 km from the nearest tourist town of Foumban. Its geographical coordinates fall under 5° 16′ to 5° 35′ N; 10° 30′ to 10° 45′ E; 1100-1300 masl with 120 m (390 ft) elevation for a total surface area of 579 $Km^2$ (Figure 19). The annual rainfall varies between 2500 and 5000mm of precipitation per year (Sonchieu *et al* 2018). The soils are mostly of volcanic origin and essentially consist of tropical ferruginous soils with little leaching and black with a high agronomic value given their richness in nitrogen, phosphorus and potassium. Regarding the hydrography of the locality, the main limit on the west side of the town is materialized by the Noun River, Foumbot's main hydrographic resource. Small streams of lesser importance also exist and are complemented by the Nkoup river which crosses a large part of the town longitudinally. There are two seasons: the rainy season which runs from mid-March to mid–November and a short dry season which takes place between mid-November and mid–March. The population that is mainly farmers is estimated at 90,406 inhabitants. More than half of the people live in a rural area where farming is the main activity. Ethnic groups in Foumbot are the Bamoun’s, Bamiléké’s, Banso’s and Mbororo’s. Foumbot is a major sweet pepper and other vegetables growing zone in Cameroon (Sonchieu *et al* 2018; Tarla *et al*., 2015). For this work, the following villages (cycled in read colors: figure) were visited: Fossang, Kouffen and Soukpen.




: ***Mfessang, Soukpen, Nkoufen***

**Figure 19:** Location of the study area (Sopkoutie *et al*., 2021).

### II.1.2 Data Collection

A total number of 110 farmers were interviewed using a pretest questionnaire and 92 farmers were finally selected to be part of the sampling population. They were interviewed from the 5th May 2020 to the 5th June 2020. The following criteria were used to select the sample: hold a farm of sweet pepper; having cultivating sweet pepper for at least one year. After selection, 46 questionnaires were administered to them. The questionnaire was made up of open and closed questions based on identification data, seeds and tools, work practices, and experiences.

### II.1.3 Statistical analysis

Data from the survey were manually codified, computerized and processed using Excel software 10.0. Statistical data analysis was performed using the package SPSS 16.0 software. A descriptive statistical analysis was done to generate frequencies.

## II.2 Composting of cassava peels

### II.2.1 Compost Preparation

Fresh cassava peels were collected from various sources within the subregion of Yaounde (Cameroon) .The obtained cassava was air-dried for one week. Then the dried cassava peels were mechanically ground in a local mill to particles ranging 0.1 –1.5mm. Figure 20 and 21 respectively below present cassava peel before and after shredding.

**Figure 20:** Dried Cassava peels.

**Figure 21:** Cassava peels after shredded.

### II.2.2 Properties of input materials

For comparative purposes, four (4) types of compost were produced from different weight of 50kg, 70kg, 90kg and 110kg of cassava peels, labelled C1, C2, C3 and C4 respectively. Table10 shows the nutrient composition of cassava peels.

### II.2.3 Study area

Field experiments were carried out at the University of Yaounde I. The average air temperature varies from 20 to 23°C. It is governed by a humid and rainy tropical climate.

### II.2.4 Online monitoring of the composting

The process of composting was carried out in composting bins (barrels) of 120 litres for 3 months. The experiment was a randomized block design with three replicates. The temperature was measured weekly for the whole composting period (Kuba *et al.*, 2008). To prevent excessive heat loss during composting, the barrels were wrapped with plastic tilt. Additional holes were cut around the barrels to provide improved aeration and were turned once after two weeks to ensure adequate $O_2$ levels inside the barrels. The temperature was monitored at a depth of 65 cm inside the piles at 9:00 h twice every two weeks. The water content of barrels was maintained at 60% of their water holding capacity throughout the 3-months experiment and water was added depending on the level of humidity, after barrels were turned. The compost was matured by the end of the 12th weeks and the temperature dropped and remained unchanged with the compost having no peculiar smell. At the end of the composting process, three subsamples were taken randomly from within each barrel, they were bulked and homogenised, air-dried and stored for some physico chemicals, biological properties, and phytotoxicity analysis.

### II.2.5 Physical and chemical analysis

#### II.2.5.1 Moisture content

The determination of moisture content of cassava peels was run according to the method of (Misra *et al*., 2003). Cassava peels were dried at 105°C for 4 hours until constant weight. The emptied Petri dishes have been heated and weighted then 10g of samples was introduced in each petri dish and the whole was also weighted. The next step consisted of putting the petri dishes containing cassava peels in the oven at 105°C during 4 hours, then after 4 hours, the were transferred into a desiccator. After 05 minutes of cooling the whole has been weighted and the moisture content was calculated as the following formula:

Moisture content $=$ (A-B / B-C) × 100

A: Weight of Petri dishes and sample before drying.

B: Weight of the Petri dishes and the sample after drying.

C: Weight of the empty Petri dishes

### II.2.5.2 Assessment of nutrients content, heavy metal and pH of mature compost

500 mg compost sample was weighed on an analytical scale. The samples were placed into teflon vessels and 5 ml of nitric acid were added in each, which evaporated until 1 ml of nitric acid were left in each. After the completion of this phase, the teflon vessels were left to cool to room temperature. 5 ml of hydrofluoric acid and 1.5 ml of perchloric acid were added. After this phase, which took three hours, the acids were evaporated until only one or two drops of acid remained. Upon completion of this phase, the teflon vessels were left to cool at room temperature for a few minutes and then 1 ml of hydrochloric acid and 5 ml of water were added to dissolve the residue. The soil samples in the teflon vessels were stirred many times to get all the content from the plate and were then filtered through quantitative filter paper and leveled up to 50 ml of volume with distilled water (ISO 14869-1 : 2001 ). Nutrients (P, K, Ca, Mg, and Na) and heavy metal (Mn, Cu, and Zn) contents were determined by atomic emission spectrometry with inductively coupled plasma, ICP-AES

The pH measurement was carried out according to the international standard ISO 10390 (1994). 10 g of compost was weighed and introduced into an Erlenmeyer flask containing 50 ml of distilled water; then the mixture was stirred for 5 minutes and then allowed to stand for 2 hours. After standing, the pH was then measured using a HQ 11D brand pH meter.

### II.2.5.3 Measurement of electrical conductivity

To measure electrical conductivity, 20 g of compost were introduced into 100 ml of distilled water, stirred for 30 minutes and then filtered. The specific electrical conductivity of the filtered extract was measured using a Hach HQ conductivity meter 14d. (NF ISO 11265, 2005)

### II.2.5.4 Determlnation of organic carbon

The methods below were used to determine an Organic C (Corg). 50 g of compost were dried in an oven at 105 ° C and then calcined at 550 ° C for 2 hours in an oven. The percentage of total organic matter (% MOT) or of volatile solid was obtained by the difference in weighing between the mass of the sample dried at 105 ° C and the mass of the sample after calcination (Bremner *et al*., 1960) according to this formula:

$$\% \text{ MOT} = \frac{(M1-M2)}{M1} \text{ x } 100$$

M 1: a mass of the sample after heating in the oven (g);

M 2: a mass of the sample after calcination (g);

-% MOT:  percentage of dry matter content in the sample.

Total organic carbon was determined according to the formula of below:

$$\% C = \frac{(\% \text{ MOT})}{2}$$

### II.2.5.5 Total organic nitrogen content

The total organic nitrogen content was determined by the Kjeldahl method. The mineralized sample is distilled with 40% sodium hydroxide in a BUCHI K-350 nitrogen distiller. The nitrogen vapours obtained were collected in an Erlenmeyer flask containing a pinkish color mixture composed of 20 ml of 3% boric acid and 3 drops of Tashiro reagent. This mixture gradually turns yellowish-green in the case where the distilled sample contains nitrogen, as the sample dropped from the distillation column is added. The solution obtained was assayed by titrimetry with 0.1 N sulfuric acid.

The C / N ratio of the composts was calculated from the organic carbon and nitrogen values obtained. It was determined according to the formula below:

$$C/N = \frac{percentage\ of\ organic\ carbon}{\text{percentage of total nitrogen}}$$

### II.2.6 Phytotoxicity test

To evaluate the compost maturity and their phytotoxicity, a germination index and germination test were conducted with sweet pepper seeds (yelo wonder) according to respectively (Tiquia *et al*., 1996) and the method using soil (compost) of (ISTA, 1996).

### II.2.6.1 Germination Index

Compost extracts were prepared by shaking compost samples with distilled water at three different dilutions (10%, 30% and 50 %) in a wrist-action shaker for 20 min at 416 rpm, followed by filtering the slurry through filter paper (Whatman). The germination test was carried out (in triplicate) on filter paper in petri dishes. Sweet pepper seeds were placed onto filter paper, ten millilitres of aqueous extract from composts were added to dishes and the dishes were placed in the dark at 25 °C. Petri dishes with sweet pepper seeds and sterile distilled water (10 mL) was the control. The germination percentages with respect to control and relative root lengths were determined after 14 days. The GI was calculated as **GI = %G ×Le/Lc**, where **%G** is the percentage of germinated seeds in each extract with respect to control, **Le** is the mean

total root length of the germinated seeds in each extract and Lc is the mean root length of the control. The control GI value is considered as 100%. Seeds were considered to be germinated if the radicle was 5 mm long (Martin *et al.*, 2014).

### II.2.6.2 Emergence test

For comparative purposes and to estimate the value of the composts, four weights of composts, sampled from the produced composts, in proportion of 1kg, 2kg, 4Kg and 6kg were introduced respectively in four buckets of 10 litres labelled B1, B2, B3 and B4 with three replications. The bottoms of each bucket was aerated with five holes .Then, 400 seeds of sweet pepper in replicates of 100 were randomly counted from the well-mixt pure seed. Afterward, replicates were divided into split replicates of 50 seeds to ensure adequate spacing and were sown concentrically in each bucket. After that, all the treatments were placed in direct sunlight (temperature: 25ºC). The buckets were continuously watered with distilled water (pH: 6.5), in accordance to the moisture content of the composts, during the test period to avoid composts to be dried out. The first count of the germination seed started after 7 days and the final count after 14 days. The rate of the germination test was calculated as the average of 400 seeds replicates and the below formula was used:

$$Percentage\ emergence\ = \frac{number\ of\ emergenced\ seeds}{\text{number of seeds sown}}\ X\ 100$$

### II.2.7 Determination of fungal and bacterial proportion in compost

The analysis of fungal population was carried out according to the suspensions-dilutions technique (Rapilly, 1968), on medium agar Potato dextrose agar (PDA) added to an antibiotic (Gentamicin). In a 250 ml Erlenmeyer flask containing 90 ml of distilled water sterile, 10 g of dry compost was added aseptically (after drying at 30 °C overnight). This mixture was stirred mechanically with magnetic bars for 30 minutes to suspend the compost particles and the spores and mycelia attached thereto. The suspension obtained corresponds to the $10^{-1}$ dilution. 1 ml of the $10^{-1}$ dilution was removed aseptically and put in 9 ml of sterile distilled water thus giving the $10^{-2}$ dilution which was stirred for two minutes before taking 1 ml which was added to 9 ml of water sterile distilled and so on until dilution 10-8. 0.1 ml was taken from each dilution, operating from $10^{-8}$ dilution to the $10^{-1}$ dilution, and seeded onto the culture media, using a sterile glass bent pipette. Petri dishes were incubated at 26 ° C for 3 days. The fungal load was

determined by colony counting and the results were expressed in CFU (Colony Forming Units) / g of compost according to the mathematical formula below.

$$\boldsymbol{N = \frac{\Sigma\ \mathbf{colonies}}{\mathbf{2Vml\ x(n1 + 0.1\ n2)}}\ \mathbf{x\ d1}}$$

N: Number of CFU per gram of compost; Σ colonies: Sum of colonies of interpretable petri dishes; V: Volume of solution deposited (1ml); n1: Number of petri dishes considered at the first dilution retained; n2: Number of petri dishes considered at the second dilution retained; d1: Factor of the first dilution retained. Only Petri dishes counting between 15 and 150 colonies at two successive dilutions were selected for enumeration (Dutruc-Rosset, 2003).

The determination of the total bacterial flora was carried out according to the technique of suspensions-dilutions on solid medium, nutrient agar added to an antifungal agent: 0.5% nystatin. 5 g of each compost was placed in a 100 ml Erlenmeyer flask containing 45 ml of sterile physiological saline (9 g of NaCl / L of distilled water) and suspended with a magnetic stirrer for 30 minutes. The suspension is then decanted for 20 minutes, then the supernatant is removed, and it constitutes the 10-1 dilution. From this suspension, decimal dilutions are made up to 10-8. 0.1 ml is taken from each dilution, operating from 10-8 dilution to 10-1 dilution, and seeded onto the culture media, using a sterile glass bent pipette. The petri dishes were incubated at 30 °C for 24 hours (Funder, 1953).
The bacterial load was determined by colony counting and the results were expressed in CFU (Colony Forming Units) / g of compost according to the mathematical formula below.

$$N = \frac{\Sigma\ \text{colonies}}{2\text{Vml x(n1 + 0.1 n2)}}\ \text{x d1}$$

### II.2.8 Statistical analysis

Data obtained were subjected to a two-way analysis of variance (ANOVA) followed by a Tukey's B-test at 5% level. The data were analysed using SPSS Software Package 16.

## II.3 Pots and field experiments

### II.3.1 Plant material collection and *O. gratissimum* leaves aqueous extraction

The leaves of fresh plants of *O. grastissimum* were collected from the city of Monatele located at the center of Cameroon, around households and the specimen confirmed at the Cameroon

National Herbarium in Yaoundé according to the deposited Voucher specimen (No Letouzey 5817/SRF/Cam.-1966).Then the fresh leaves were dried at room temperature (25ºC) for three weeks. To prepare the aqueous extract of *O. gratissimum,* 50g of the powder of the dried leaves were weighted and soaked into 1l water for 24 hours before being filtered. The supernatant was used as a biopesticide and bioinsecticde spray for plants.

### II.3.2 Sweet pepper seeds variety

Sweet pepper seeds of variety Yolo Wonder used were bought from one of the agro shops of Mokolo market (Yaounde-Cameroon).

### II.3.3 Mineral fertilizer and chemical insecticide

Mineral fertilizer (NPK: 20.10.10), insecticide (K-optimal) and fungicide (mancozeb) were bought from one of the agro shops of Mokolo market (Yaounde-Cameroon).

### II.3.4 Experimental site

The study was carried out from June to September 2020 at Nkolbisson (3˚52'N and 11˚27'E) peri-urban vegetable farming sites, West of Yaounde. The annual rainfall distribution is bimodal, lighter rains between March and June and a more intense rainy season between September and November, with peak rainfall in May and October. The area has a mean annual rainfall of approximately 1500-2000mm and a mean annual temperature of 24.7°C. The relative humidity range between 50 and 80% in the dry season and 70 and 90% in the rainy season. The type of soil is ferritic with a pH of 6.5.

### II.3.5 Nursery

Sweet pepper seeds were sown in nursery beds enriched with the mixture of cow dung powder at the dose of 250 g/m$^2$ (Mangoumou *et al.,* 2020). The seedlings used were 45 days old and had four to five true fully expending leaves. They were transplanted simultaneously in an open-field and the pot experiment on 5th July 2020.

### II.3.6 Experimental design

#### II.3.6.1 Pot experiment

The pot experiment was laid out in a split splot design, with 4 blocks. Each block had 3 plots (09 buckets of 5 liters) with three repetitions. Each plot contained 03 buckets with one sweet

pepper plant each. The interval of 40 cm was in between plots. The pot experiment contained an overall of 36 buckets that were aerated with 5 holes in the bottom.

#### II.3.6.1.1 Soil sampling, composts, sand and soil mixing

The soil used for the pot experiment was sampled from the field experiment site at a depth of 0-20 cm in three different areas diagonally (Mangoumou *et al* 2020). All sampled soils were mixed to form a composite soil. The soil characteristics are presented in table 15. The sand used was the Sanaga sand.

In general, the pot experiment had 36 plastic buckets. 1kg and 2kg of composts respectively collected from C1 and C2 were respectively mixed separately with the composite soil in ratios of 1:4 and 2:3 (Kg/ kg). Then, each mixture was respectively transferred in 09 plastic buckets of 5liters, which overall gave 18 plastic buckets. Then, 26.3g of NPK (20.10.10) was also mixed with soil and sand in a ratio of 3:2 (Kg/kg) and introduced in 09 plastic buckets of 5liters. Finally, a mixture of soil and sand in a ratio of 3:2 (Kg/kg) without any amendment (control) was introduced in 09 plastic buckets of 5liters (Figure 22).

### II.3.6.2 Field experiment

The field experiment was also laid out in a split splot design with 4 blocks. Each block had 3 plots with three repetitions. Each block contained 54 sweet pepper plants, given, 06 sweet pepper plants per plot. Sweet pepper seedlings transplanting was done at an interval of 40 cm in between seedlings and 50 cm between plots. Each plot of the first and the second block was respectively amended with 3Kg and 6kg of composts collected from C3 and C4. On the other hand, 06 holes were dug on each plot of the third block and received an amendment of 26.3g of NPK (20.10.10) one week before seedlings transplantation and the fourth block remained without any amendment (control) (Figure 22).

## II.3.7 Treatments in pot and field conditions

In total, there were 12 treatments, and each of them had three replications (Table 4)

**Table 4:** Treatments of soil amendment and spraying of sweet pepper plants

| | **Soil amendment** | | **Plant spraying** |
|---|---|---|---|
| **Treatments** | **Pot experiment** | **Field experiment** | **Pot and field experiments** |
| **CP1-B** | Compost at 1kg/4kg of a mixture of soil (3kg) and sand (1kg) | Compost at 3kg/plot | 5% of aqueous extract of *O. gratissimum* |
| **CP1-E** | | | Water |
| **CP1-S** | | | K-optimal (40mL /sprayer of 15 L): and mancozeb(100mg /sprayer of 15 L) |
| **CP2-B** | Compost at 2kg/3kg of a mixture of soil (2kg) and sand (1kg) | Compost at 6kg/plot | 5% of aqueous extract of *O. gratissimum* |
| **CP2-E** | | | water |
| **CP2-S** | | | K-optimal (40mL /sprayer of 15 L): and mancozeb(100mg /sprayer of 15 L) |
| **NPK-B** | 26.3g of NPK (20.10.10) per plant | 26.3g of NPK (20.10.10) per plant | 5% of aqueous extract of *O. gratissimum* |
| **NPK-E** | Positive control | | water |
| **NPK-S** | | | K-optimal (40mL /sprayer of 15 L): and mancozeb(100mg /sprayer of 15 L) |
| **C–B** | Soil without any amendment | Soil without any amendment | 5% of aqueous extract of O. gratissimum |
| **C–E** | Negative control | | Water |
| **C–S** | | | K-optimal (40mL /sprayer of 15 L): and mancozeb(100mg /sprayer of 15 L) |

All plants undertaken in this study received the regular agricultural and horticultural practices that usually carried out in the vegetable crops such as hilling, hoeing and weeding. Foliar sprays started a week after transplantation and were performed until harvest of fruits, they were made every two weeks for pot experiment, and every one week for field experiment, using knapsack sprayer. Spraying was performed in the morning around 8.am, under steadywind condition, and the whole sweet pepper plant (leaves, stems and fruit) was sprayed.

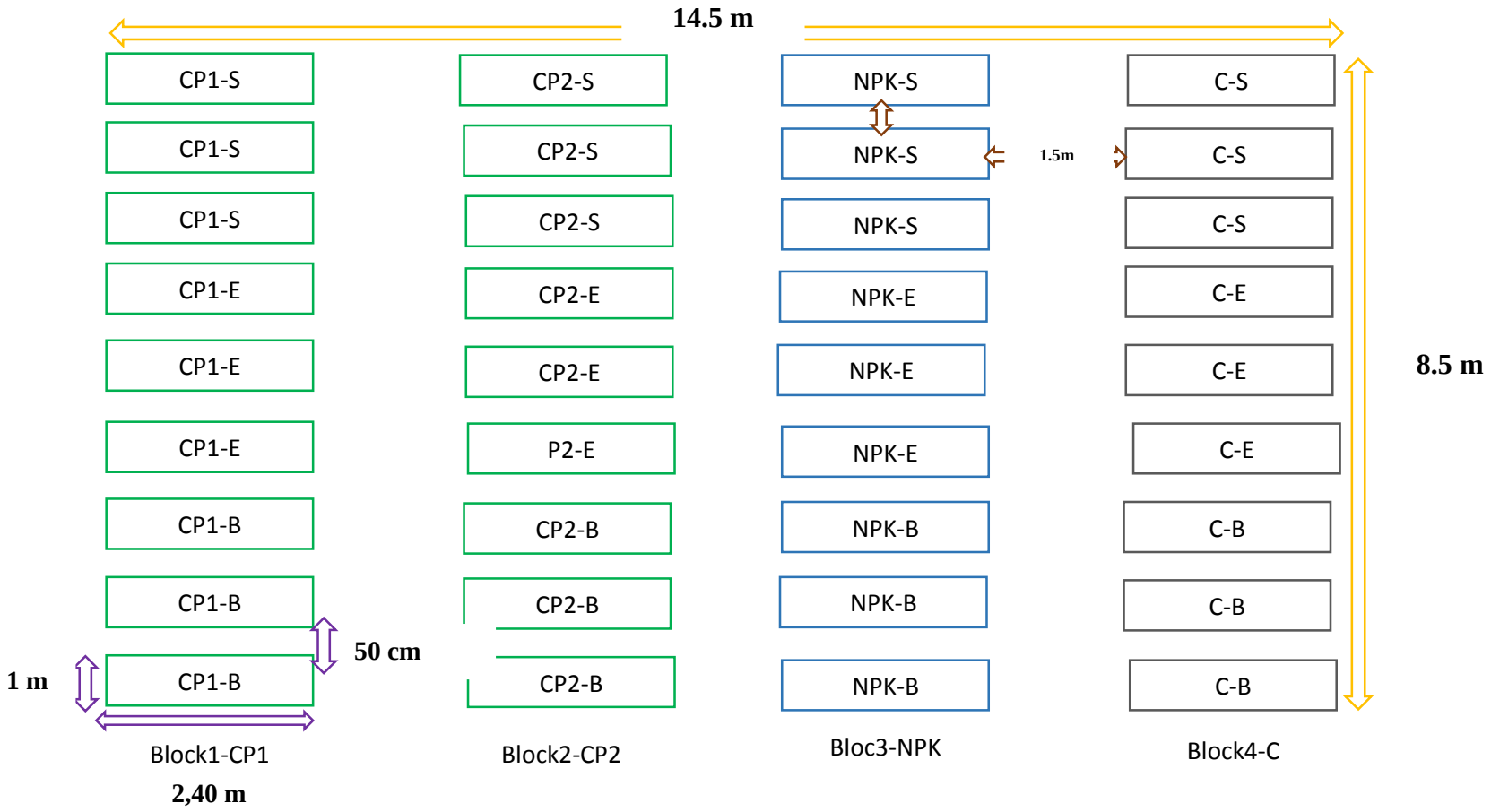



**Figure 22:** Experimental design

### II.3.8 Agronomic measurements

#### II.3.8.1 Vegetative growth characteristics

During and at the end of the experiment three sweet pepper plants per replicate of each treament were randomly selected and the data were collected on the following parameters: (1) (Plant height (cm), (2) the number of leaves per plant (3) Crown diameter per plant (cm) and (4) the number of branches per plant. When plants began blooming, counting of the blooming plants started in each replicate every day, until 50 percent of the plants per replicate were in bloom (number of days that 50% of the plants will give flowers), (Taleb Abu-Zahra, 2012).

#### II.3.8.2 Yield characteristics

##### II.3.8.2.1 Total yield

The total yield was measured directly in the field by weighing the total freshly harvested fruits per replicate, using a digital scale balance. At the end of the experiment, all weights for each replicate were summed. (Taleb R. Abu-Zahra, 2012). Total fruits harvested from each treatment along the harvesting period were divided on the plants' numbers per treatments to calculate the fruit number/plant. (Mohammed, 2013).

#### II.3.8.3 Physical fruits quality

Ten fruits from each treatment were randomly taken for determining the average fruit character as follows ( Mohammed, 2013): fruit length (cm) and fruit diameter (cm).

### II.3.9 Assessment of the incidence and severity of attacks

The plants were rated for disease incidence (DI) and disease severity (DS). DI as the presence or absence of disease (percentage of infected leaves on the plant) and DS as the severity percentage of disease damage on sweet pepper plants. Disease incidence and severity was assessed whithin three months after transplanting.The observation on number of wilted plants was recorded at weekly interval till completion of crop season and disease incidence in each treatment was calculated by following formula (Kaushal Attri *et al.,* 2019):

$$Disease\ Incidence\ (\%) = \frac{\text{Number of wilted plants}}{\text{Total number of plants observed}} \text{X } 100$$

Severity of symptoms on individual plants was rated using the devised scale (0 to 5) by Amini and Sidovich (2010) on the foliage growth using the following scale:

Where:

0 = No foliar symptoms,

1 = Chlorosis and/or wilt restricted to first leaf,

2 = Chlorosis and/or wilt extending beyond the first leaf,

3 = Moderate to severe foliar symptoms usually with some abscised leaves,

4 = Severe foliar symptoms on the entire plant,

5 = Dead plant.

$$Disease\ severity\ \% = \frac{£\ (\mathrm{nxv})}{5\mathrm{N}} X\ 100$$

Where:

n = Number of infected leaves in each category.

v = Numerical values of each category.

N = Total number of the infected leaves.

### II.3.10 Fruit harvesting and analysis

#### II.3.10.1 Fruit harvesting

Sweet peppers fruits were harvested at the same time based on their maturity (mature green). Immediately after harvesting, the fruit samples were taken from each experimental plot and transported to the laboratory where the peppers were carefully selected to ensure that fruits free of defects such as injured fruits, softening, surface pitting were chosen. (Alicia Marin, 2004, Butnariu, 2014).

#### II.3.10.2 Organoleptic analysis

Organoleptic analysis of peppers was performed after 14 days of storage at 16°C (Krasniewska *et al.*, 2014) the organoleptic analysis consisted of analyzing the organoleptic properties of sweet pepper fruits by the sense organs, namely sight, taste, smell and touch. 12 panelists were chosen. To evaluate the taste, panelists evaluated all samples using the following procedure (Gillette *et al.*, 1998):

1. Cleanse palate before first sample with spring water for 60 seconds (timed).
2. Take entire 1st sample in mouth, hold for about 5 second and swallow slowly.
3. Wait 30 seconds (timed).
4. Rate 1st sample.
5. Cleanse palate with spring water for 60 seconds (timed), immediately prior to 2nd sample.
7. Take entire 2nd sample in mouth, hold for about 5 seconds, and swallow slowly.
8. Wait 30 seconds (timed).
9. Rate 2nd sample.
10. Repeat the same procedure for the other samples.

The panelists were also asked to rate the samples on color/appearance, size/shape, odor/aroma, texture and/or mouthfeel, liking, sweetness based on the 9-point hedonic scalpe ranging from (1) – Dislike extremely, (2) – Dislike very much, (3) – Dislike moderately , (4) – Dislike slightly, (5) – Neither like or dislike, (6) – Like slightly, (7) – Like moderately, (8)– Like very much, (9) – Like extremely (Meilgaard *et al*., 1999; Lawless and Heymann, 1998), as described in the Annex 6

## II.3.10.3 Shelf-life

A shelf-life study of sweet pepper fruits was conducted, according to a modified method of Rao *et al.* (2011), by collecting three selected fruits per treatment and stored respectively at 4°C in freezable polystyrene bags and under field conditions (room temperature). During storage, visual decay of fruits was evaluated until the marketing requirements were considered poor for each treatment. The number of days was counted and the mean value was obtained per treatment.

### II.3.10.4 Fruit analysis

After removing seeds and stalk from each fruit, the flesh was chopped in 5-10 mm pieces which were water evaporated. Then, 400 g aliquot from each sample was dehydrated in an oven, at a temperature of 38°C for 14 days until constant weight; next, the samples were kept at 24°C in the dry atmosphere (Butnariu, 2014). The determination of water content, pH, vitamin C, was directly run after grinding fresh sweet pepper fruits.

### II.3.10.4.1 Determination of water content

The water content was determined by the method described by A.O.A.C (1980)

**Principle**

The principle is based on the loss in mass of the samples after drying in an oven at 105 ° C until complete elimination of free water and volatile matter and the obtention of a constant mass.

**Procedure**

A dry aluminum tare was weighed (Po) as well as 5g of fresh sample (P1). They have been dried in an oven at 105 °C until a constant weight. Then the dry residue has been cooled in the atmosphere of a desiccator containing P2O5 as a desiccant for 1 hour and then weighed (P2). The water content was determined as the following formula:

$$water\ content(\%) = \frac{\mathrm{P1-P2}}{\mathrm{P1-P0}}\ \mathrm{X}\ 100$$

P0 = Weight of the dry porcelain capsule;

P1 = Weight of the fresh sample;

P2 = weight of the cooled dry residue;

The results were calculated in g per 100g of fresh material.

Three tests has been carried out and the water content was the average of the three tests

### II.3.10.4.2. Determination of ash content

The ash content was determined by the method described by A.O.A.C (1980).

**Princple**

It is based on the quantification of the ash by calcination. This is an incineration of a sample of a known mass, until the optention of carbon-free ash (white ash).

**Procedure**

A porcelain capsule , was carefully washed and rinsed with distilled water and 1% nitric acid , has been dried in an oven at 650 °C for 1 hour.Then was placed in an oven at 550 °C for 3 hours to destroy all organic matters. After that, it has been put in a desiccator for 1 hour before being weighted (P1). 3 g of dry matter (P0) from the sample was placed in the capsule and the whole has been dried at 550 °C for 48 hours. Then the capsule containing the ash were placed in a desiccator for cooling before being weighted (P2). The ash content was calculated as the below formula :

$$T = \frac{\mathrm{P2} - \mathrm{P1}}{\mathrm{P0}} \; X\, 100$$

P0: Weight of dry matter (g)

P1: Weight of the dry and cooled porcelain capsule (g)

P2: Weight of the capsule containing cooled ash (g)

The results was calculated per g per 100 g of dry matter.

Three tests has been run and the ash content was the average of the three tests.

### II.3.10.4 .3 Determination of total protein content

The protein content has been determined by the method of Kjedhal A.O.A.C (1980).

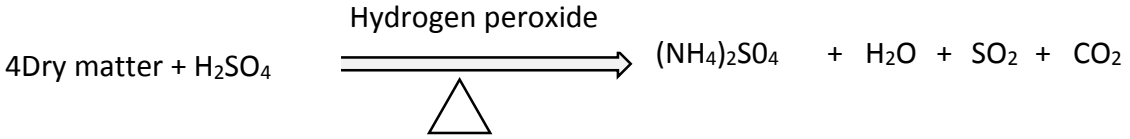
**Principle**

The principle is based on the transformation of organic nitrogen into ammonium sulfate under the action of sulfuric acid in the presence of a catalyst, and is titrate after displacement in an alkaline medium and distillation as ammonium. Then, the nitrogen (N) content is converted into crude protein by the follow formula: N x 6.25. Where 6.25 is the conversion factor of nitrogen to protein.

**Procedure**

**Step1**: Mineralization

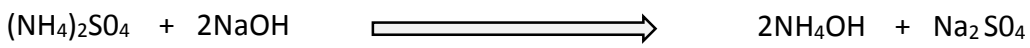
0.2 g of dry matter was introduced into each mineralization flask with a pinch of mineralization catalyst (hydrogen peroxide) and 4 ml of concentrated sulfuric acid, then were placed such that the neck of the flask was engaged in a smoke collecting tube. The heat was gradually increased withing 4 minutes so that the white smoke does not exceed ¾ of the neck of the flask. The initial syrupy black liquid gradually became light brown and colorless. The sulfuric attack took place during 4 minutes after the discoloration of the mineralized material before allowing to cool. Below is the mineralization equation :



Dry matter : organic nitrogen ; H2SO4 : sulfuric acid ; (NH4)2S04 : ammonium sulfate

**Step 2** Distillation

25 ml of distilled water has been added to each flask and placed on the distillation apparatus. Then, 75ml of 40% NaOH was added until an alkaline medium. After that, 250 ml beaker containing 5 ml of absorbent solution (4% boric acid) and three drops of thashiro colored indicator (pink coloring in acidic medium) were placed at the outlet of the refrigerent. After 2 minutes of mineralization, the thashiro colored indicator turned into green color due to the formation of the ammonium borate. Below is the distillation equation :



2NaOH : sodium hydroxyl, $2NH_4OH$ : ammonia, $Na_2S0_4$ : sodium sulfate, $H_3\ B0_3$ : Boric acid, $(NH_4)_3BO_3$ : Ammonium borate

**Titration**

The distillate obtained (ammonium borate) was titrated with 0.1 N sulfuric acid contained in a 25 ml burette (0.05 ml graduation). Then the color changed from green to pink with the formation of ammonium sulfate and regeneration of boric acid. A control flask containing no biological material, but all the other reagents, was subjected to the same procedure. It allows to evaluate the traces of nitrogen which come from the reagents. Below is the equation of the titration.

3H2SO4 : sulfuric acid

The percentage of total nitrogen contained in the sample was determined according to the below formula :

$$(\%N) = \frac{0.0014 \text{ x V}}{P} \; X\ 100$$

Where:

V = Volume of $H_2SO_4$ (0.1 N) corresponding to the concentration of ammonia in the weight dry matter (ml).

P = Weight of the mineralized dry matter in the flask (g).

The percentage of protein in each sample was obtained by multiplying the percentage of nitrogen by the factor 6.25 (Zou et al. 2015) as the following formula.

Percentage of crude protein (%) = percentage of total nitrogen X 6.25

The results were expressed in g per 100 g of dry sample.

**II.3.10.4.4 Determination of the total sugars content**

The total sugars content was determined by the phenol test of Godon B and Loisel W. (1997).

**Principle**

In the presence of concentrated sulfuric acid, the oses will be dehydrated into compounds of the family of furfuralic derivatives. Those compounds condense with the phenol to give yellow-orange complexes. The amount of sugars is read with a spectrophotometer at a wavelength of 490nm.

**Procedure**

Extraction of sugars10 ml of a mixture of hydroalcoholic (1/10 v / v) was introduced in a beaker containing 100 mg of sample. Then the whole was homogenized for 10 minutes before being filtered and evaporated at room temperature to remove the excess solvent and the filtrate obtained was used for the analysis.

**The calibration curve**

From a standard solution of glucose (1 mg / ml), 0.07; 0.14; 0.21 and 0.28 ml were collected and introduced into the tubes. The calibration curve of the glucose was done as presented in the below table 5.

**Table 5: Glucose calibration curve**

| | control | Tub 1 | Tub 2 | Tub 3 | Tub 4 |
|---|---|---|---|---|---|
| Glucose (ml) 1 mg / ml | / | 0,07 | 0,14 | 0,21 | 0,28 |
| Phenol 5% (ml) | 0,3 | 0,3 | 0,3 | 0,3 | 0,3 |
| Distilled water (ml) | 0,4 | 0,33 | 0,26 | 0,19 | 0,12 |
| Solution of concentrated sulfuric acid (ml) | 1,8 | 1,8 | 1,8 | 1,8 | 1,8 |
| Immediate reading of absorbances at 490 nm against blank | | | | | |

**Dosage**

1 ml of hydroalcoholic extract was introduced into the test tubes, inclunding 0.4 ml of distilled water and 0.3 ml of 5% (w / w) phenol. The whole was homogenized, and 1.8 ml of sulfuric acid has been added to the mixture. The obtained optical densities of the solutions was immediately read with a spectrophotometer at 490 **nm against the control.** The dosage was carried out in triplicate.

The sugar content of each test sample was determined using the glucose calibration curve equation y = 3.6021 x +0.0011. The results was expressed in g per 100 g of the dry matter.

**II.3.10.4.5 Total lipid content**

The total lipids have been extracted according to the method described by Bourely (1982).

**Principle**

The extraction is based on the differential solubility of lipids in organic solvents (hexane or petroleum ether). It is done in a hot temperature during 8 hours. After that, the solvent is removed by evaporation and the oil is dried in an oven.

**Procedure**

The filter papers have been dried in an oven at 105 $^{0}$C for 2-3 hours and weighted (PF). Then 2 g of dry sample was weighed (PB) and put in filter papers before being dried in an oven for 24 hours. After drying, the whole was weighed (PA).

The filter papers containing the samples were placed in the extractor for 12 hours to extract the oils with hexane as the solvent. 12 hours later, the samples have been removed from the

extractor and dried in an oven at $105^0$C for 3 hours and the weighted (PE). The procedure has been run three times. The total lipid content has been calculated as the below formula.

$$\text{Total lipid content}(\%) = \frac{\text{PA} - \text{PE}}{\text{PA} - \text{PF}} \; X\; 100$$

PA = Weight of filter papers and dry samples (g)

PE = Weight of filter papers and delipidated and dried samples (g)

PF = Weight of dried filter papers (g).

The results were expressed in g per 100 g of dry matter.

**II.3.10.4.6. Determination of crude fiber content**

Crude fibers were determined by the method described by A.O.A.C (1990).

**Principle**

This method is based on a succession digestion of the sample with strong acids and strong bases.

**Procedure**

1 g of delipidated dry matter (P1) has been introduced into a 200 ml beaker and 100 ml of 0.26 N sulfuric acid were also added. The beaker has been placed on a hot plate at 1000 $^0$C for 30 minutes, then its contents was filtered and washed 3 times with distilled water. Then, 100 ml of 0.23 N potassium hydroxide (KOH) have been added to the beaker and the whole was placed on a hot plate for 30 minutes. After that, the contents were filtered and washed 3 times with distilled water and 2 times with acetone and dried in a porcelain dish at $105^0$C for 8 hours, then were placed in a desiccator for cooling before being weight( P2). The capsule was then introduced into an oven at 500 °C for 3 hours then cooled in a desiccator and weighed (P3). The crude fiber content has been calculated as the below formula.

$$\text{crude fiber content}\ (\%) = \frac{\text{P2} - \text{P3}}{\text{P1}} \; X\; 100$$

P1 = Weight of delipidated dry matter (g)

P2 = Weight of contents of the beaker dried in a porcelain (g)

P3 = Weight of the oven-dried and cooled capsule (g).

The results have been expressed in g per 100 of dry matter.

### II.3.10.4.7 Evaluation of the mineralogical composition

The macromineral content was evaluated by the flame atomic absorption spectrophotometry method of Benton and Vernon (1990).

**Principle**

The liquid sample is vaporized and heated with a flame. The flame is directed towards a light emitted by a suitable lamp, which produces the characteristic wavelengths of the desired element. As they pass through the flame, the light waves, whose wavelengths correspond to the element being dosed, are absorbed by the excited ions present in the flame. The measured absorbance is directly proportional to the concentration of the element.

**Procedure**

**Preparation of solutions**

Aqua regia solution: 1.2 l of deionized water was introduced in a 2l volumetric flask. Then 400 ml of concentrated hydrochloric acid and 133 ml of 70% nitric acid has been added and the volume was completed to the mark with the deionized water.

**Strontium chloride solution:**

5.75 g of $SrC_{l2}$, $6H_2O$ have been weighed and dissolved in a beaker containing deionized water, then introduced into a 2l volumetric flask and the volume made up to the mark with deionized water.

**Mineralization**

0.5 g of the dry delipidated sample was weighed and then placed in a porcelain dish washed and rinsed with 10% of nitric acid before being respectively dried in an oven for 30 minutes and for 3 hours. An empty capsule served as control. Then the capsules were placed in the oven at $500^0$C for 24 hours and cooled in an environment free from any humidity in order to obtain a whitish ash. In addition, the capsules have been rinsed with 15 ml of aqua regia solution in 50 ml propylene tubes. Using a mechanical stirrer, the mixture was stirred for 10 minutes and then centrifuged at 3000 rpm for 10 minutes as well. The supernatant which is the sample solution was collected for the analysis.

**Samples preparation**

To determine the macroelements (Ca, Mg, K, Na), 0.5 ml of the supernatant were diluted in 19.5 ml of strontium chloride solution. For the determination of trace elements (Cu, Fe, Mn, Zn), the supernatant were not diluted and approximately 10 ml have been used. 2 tubes containing the same quantities of the products like all the other tubes and made up to volume with deionized water were added for each series of the analysis.

Standards, samples and blanks were then introduced through a flame atomic absorption spectrophotometer. three tests were carried out for each mineral The calibration curve for each standard was used to determine the concentration (mg / 100g DM) of each mineral in the tests using the equation of each curve.

**Phosphorus content**

The phosphorus content was determined by the colorimetric spectrophotometric method of Murphy and Riley (1962).

**Principle**

In an acidic and reducing medium, the phosphate ions together with ammonium molybdate form a blue phospho-molybdate ammonium complex, which the absorbance is proportional to the phosphorus concentration at 860 nm.

**Procedure**

**Preparation of solutions**

Stock Solution: Murphy-Riley Stock Solution was prepared by gradally adding 140 ml of concentrated $H_2SO_4$ into approximately 1 L of deionized water contained in a 2 L volumetric flask. In a beaker, a solution of 12 g of ammonium molybdate was prepared in 250 ml of deionized water. And 0.291 g of antimony potassium tartrate was prepared in 100 ml of deionized water. The whole was mixed with the solution containing the $H_2SO_4$ and the volume made up to 2 l.

Working solution: it was obtained by mixing 1.056 g of ascorbic acid dissolved in 1 liter of deionized water with 200 ml of Murphy-Riley stock solution. Then the obtained solution was slightly yellow.

0.25 ml of each sample solution and 19.75 ml of the working solution (solution 2) were diluted into 25 ml tubes. The color of the solutions in all tubes (standard and blank samples) have been allowed to be develop for 30 minutes and the absorbance was read at 860 nm against the blank using a colorimetric spectrophotometer. The analyzes have been carried out in triplicate.

### II.3.10.4.8 Titration of vitamin C

**Experimental Procedure**

**Standardization of the iodine solution**

Three samples of solid ascorbic acid (0.05g ) were weighted. Then each sample was placed in a numbered 125 ml Erlenmeyer flask before adding 30ml distilled water and 5 drops of starch solution to each flask.

**Titration of the ascorbic acid solution**

Rinse and fill a 25ml of buret was rinse and filled with the iodine solution and the ascorbic acid solution was titrated and the initial and final volume readings from the buret was recorded. After collecting the data, the molarity of the iodine solution was calculated. The prcedure was reapeated for the other two ascorbic acid solution.

**Titration of the extract**

10 mg of the sample was grinded and mixed with 10 ml of distilled water. The obtained mixture was homogenized then centrifuged at 6000 rpm for 10 min. Then the supernatant was collected. 20 mL of the supernatant was introduced into a 125 mL Erlenmeyer flask before adding repectivelly 25 mL of distilled water and 1 mL of starch indicator solution. Then, the titration was run by dropping the standardized iodine solution into the Erlenmeyer flask still the endpoint of the titration occured ( permanent dark blue-black color due to the starchiodine complex). The titration was repeated tthree times for each sample.

The table 6 and formula below have been used to calculate the concenration of vitimin c.

**Table 6: Dosage of vitamin C: parameters**

| Mass of ascorbic acid used, (g) | Initial Volume of Iodine Solution, (mL) | Final Volume of Iodine solution, (mL) | Volume of Iodine Solution used, (mL) | Concentration of Iodine Solution, (M) |
|---|---|---|---|---|
| | | | | |
| Volume of fruit extract used, (m) | Initial Volume of Iodine Solution, (mL) | Final Volume of Iodine solution, (mL) | Volume of Iodine Solution used, (mL) | Concentration of Ascorbic Acid in Sample, (mg) |
| | | | | |

### II.3.10.4.9 Assessment of total polyphenol content, total flavonoid content and antioxidant potential

**Extract preparation of sweet pepper fruits**

2g of powder materials of sweet pepper fruits were added to 30 ml of hydroethanolic solvent (30:70v/v). Then, the mixture was stirred during 2 hours through a magnetic stirrer before being filter with a filter paper. The obtained filtrate was stored in dark bottles at −20°C till further analysis. The extraction process was done in triplicate (Vinson *et al*.,1998).

#### II.3.10.4.9.1 Total polyphenol content assessment

Total phenolic content was determined following the method described by Singleton and Rossi (1965) with some modifications. Folin-Ciocalteu reagent was used with gallic acid as the standard phenolic compound. About 0.5 mL of an extract was introduced into test tubes followed by 2.5 mL of 10% Folin-Ciocalteu reagent. The tubes were vigorously homogenized on a shaker and the mixture was allowed to stand for 30 minutes and absorbance read at 765 nm. Total phenol content was expressed as milligram of gallic acid equivalent (GAE) per gram of dry matter extract (mg GAE/ gDM).

#### II.3.10.4.9.2 Total flavonoid content assessment

The colorimetric method described by Aiyegoro and Okoh (2010) with Aluminum Chloride was used to evaluate the total flavonoid content. To 0.2 mL of aluminum chloride (AlCl3, 10%), was added 0.2 mL aliquot of an extract followed by the successive addition of 0.2 mL of potassium acetate (CH3COOK, 1M) and 1.12 mL of distil water. The whole mixture was well homogenized and incubated at room temperature and the absorbance was read at 415 nm against

the reagent blank 30 minutes later. Quercetin (0-1000 µg/mL) served as a standard and the results were expressed as (mg QE/ gDM).

#### II.3.10.4.9.3 Evaluation of antioxidant potential

##### II.3.10.4.9.3.1 Trapping of the radical DPPH (2,2-diphenyl-1-picrylhydrazyl)

The radical scavenging activity of fruit was assessed using the 2, 2′-diphenyl-1-picrylhydrazyl (DPPH) test as described by Brand *et al*., 1995.

An extract (50 µl) was added to 2.95 ml of an ethanolic solution of DPPH (55 µM), kept in the dark for 15 min at room temperature and then the decrease in absorption was measured at 517 nm using a UV–Vis spectrophotometer. Absorption of blank sample containing 50 µl of ethanol 80% and 2.95 ml of an ethanolic solution of DPPH was prepared and measured. The experiment was carried out in triplicate. Ascorbic acid was used as the standard antioxidant. The Radical scavenging ability of the extracts was calculated as:

DPPH radical scavenging activity (%) = $((Abs\ of\ control - Abs\ of\ sample)/Abs\ of\ control) \times 100$

##### II.3.10.4.9.3.2 Determination of Total Antioxidant Capacity

Total antioxidant activity of extract was evaluated by the formation of phosphomolydenum complex (Prieto *et al.,* 1999). To this effect, 0.1 ml solution of extract was added to 1.9 mL of reagent solution (0.6 M H2SO4, 28 mM sodium phosphate and 4 mM ammonium molybdate). The absorbance was measured at 695 nm after boiling for 60 minutes. Ascorbic acid was used as a standard and total antioxidant capacity was expressed as micrograms of ascorbic acid equivalent (AAE) per 100 g of extract of dry matter (mg AAE/g DM).

##### II.3.10.4.9.3.3 Reducing Ferric Capacity (FRAP: Ferric Reducing Antioxidant Power)

The method of Oyaizu (1986) was used to assess the reducing power of the fruit peelings extracts. A volume of 1 ml of extract was mixed with 2.5 ml of a 0.2 M sodium phosphate buffer (pH 6.6), 2.5 ml of 1% potassium ferrocyanide and incubated in a water bath at 50 °C for 20 min. Then, 2.5 ml of 10% trichloroacetic acid was added to the mixture that was centrifuged at 650 rpm for 10 min. The supernatant (2.5 ml) was then mixed with 2.5 ml distilled water and 0.5 ml of 0.1% ferric chloride solution. The intensity of the blue-green colour was measured at 700 nm. Ascorbic acid was used as positive control at concentration ranging from 0 to 0.30 mg/ml.

### II.3.10.4.10 Determination of pesticide residue: QuEChERS Methodology (AOAC Method, 2007)

Three samples of sweet pepper fruits were taken from each treatment. The equipment used for the harvest of sweet pepper fruits was previously cleaned with water and gloves to avoid any contamination. Samples from each treatment were packaged in aluminum foil and freezer plastic bags, labelled, and transported the same day to the MINADER Laboratory, in a cooler containing small ice plastics. In the laboratory, samples were stored at -21°C in a refrigerator (Mahugija, 2017).

Sample extraction and dispersive solid-phase extraction (d-SPE) sample clean-up were run using the QuEChERS method and analysed by gas chromatography coupled to a detector (Agilent 5975 C TAD VL MSD). Each sample (two fresh sweet pepper fruits per treatment) was cut into a small pieces and ground using respectively a knife and a household grinder. Each time the grinder was thoroughly washed to avoid cross-contamination between samples. After grinding, 15 g of homogenized product was weighed into a clean 50 mL tube and 15 mL of 1% acetic acid in acetonitrile (v/v) was added and an appropriate amount of an internal standard solution. After that, (6.0 g ± 0.3 g) of anhydrous magnesium sulfate and 1.5 g sodium acetate was added into the tubes to remove water in the sample. The content of the tubes was homogenised and vortexed for 1 min. This was followed by the centrifugation at 4000 rpm for 1 min. To remove any organic acids, polar pigments, and other compounds that could interfere with the analysis, 8 mL of the supernatant was collected and introduced into 15 mL d-SPE tube containing 1.2 g of MgSO4 and 0.4 g of primary secondary amines (PSA). Then the tube was vigorously mixed for 30 s, vortexed for a minute before the centrifugation at 400 rpm within 1 minute. Supernatant (01 mL) was introduced into a 1.5 mL chromatography vial for injection on gas chromatography.

**Principle of gas chromatography**

The sample solution injected into the instrument enters a gas stream which transports the sample into a separation tube known as the "column." (Helium or nitrogen is used as the so-called carrier gas.) The various components are separated inside the column. The detector measures the quantity of the components that exit the column. To measure a sample with an unknown concentration, a standard sample with known concentration is injected into the instrument. The standard sample peak retentiontime (appearance time) and area are compared to the test sample to calculate the concentration.

## Gas chromatography

The apparatus used was an Agilent Technology 7890A gas chromatograph comprising an automatic injector G4513A, an Agilent 5975 C TAD VL MSD mass detector equipped with three detection axes, and an Agilent J and W GC capillary column of 30 m length, 0.250 mm diameter and a film of 0.25 µm. This equipment was controlled by a microcomputer equipped with The Agilent GC Chemstation Plus version G1701EA E.02.02.1431 software. The injection (1 µl) was carried out in spitless mode and helium was used as carrier gas at 1.2 mL/min (column flow rate). The operating conditions of the GC were as follows: initial temperature of the injector: 150°C; temperature of the detectors: 310°C; the column was initially set at a temperature of 70°C, then increased at a rate of 25°C/min to 280°C and held for 5 min.

### II.3.11 Soil sampling and analysis

#### II.3.11.1. Soil sampling

From each plot, soil was sampled at a depth of 0-20 cm in three different areas diagonally. All sample soils were mixed to form a composite. 1/2 kg of the composite was air-dried, ground, and sieved (<0.25 mm), then serve as a substrate for the physicochemical analysis. A part of the composite was sieved (<0.5 mm) and then stored at 4°C until total flora analysis.

#### II.3.11.2. Soil physicochemical analysis

## Nutrients and heavy metal contents

500 mg soil sample was weighed on an analytical scale. The samples were placed into teflon vessels and 5 ml of nitric acid were added in each, which evaporated until 1 ml of nitric acid were left in each. After the completion of this phase, the teflon vessels were left to cool to room temperature. 5 ml of hydrofluoric acid and 1.5 ml of perchloric acid were added.

After this phase which took three hours, the acids were evaporated until only one or two drops of acid remained. Upon completion of this phase, the teflon vessels were left to cool at room temperature for a few minutes and then 1 ml of hydrochloric acid and 5 ml of water were added to dissolve the residue. The soil samples in the teflon vessels were stirred several times to get all the content from the plate and were then filtered through quantitative filter paper and leveled up to 50 ml of volume with distilled water (ISO 14869-1, 2001 ). Nutrients (P, K, Ca, Mg, and Na) and heavy metal (Mn, Cu, and Zn) contents were determined by atomic emission spectrometry with inductively coupled plasma, ICP-AES.

**pH**

The pH measurement was carried out according to the international standard ISO 10390 (1994). 10 g of soil was weighed and introduced into an Erlenmeyer flask containing 50 ml of distilled water; then the mixture was stirred for 5 minutes and then allowed to stand for 2 hours. After standing, the pH was then measured using a HQ 11D brand pH meter.

**Electrical conductivity**

To measure electrical conductivity, 20 g of soil were introduced into 100 ml of distilled water, stirred for 30 minutes and then filtered. The electrical conductivity of the filtered extract was measured using a Hach HQ conductivity meter 14d. (NF ISO 11265, 2005).

**Cation exchange capacity (CEC)**

Cation exchange capacity (CEC) was determined by percolating 2.5g of soil with 100mL of 1N ammonium acetate buffered at pH 7, removing the excess with ethanol and displacing the absorb NH4+ ions with 1N KCl, determining the collected NH4+ ions by distillation and titration with 0.01N sulfuric acid

**Organic C (Corg)**

To determine Organic C (Corg), 50 g of compost were dried in an oven at 105 °C and then calcined at 550 °C for 2 hours in an oven. The percentage of total organic matter (% MOT) or of volatile solid was obtained by the difference in weighing between the mass of the sample dried at 105 °C and the mass of the sample after calcination (Bremner *et al*., 1960) according to this formula:

$$\% \text{ MOT} = \frac{(M1-M2)}{M1} \times 100$$

M 1: a mass of the sample after heating in the oven (g);

M 2: a mass of the sample after calcination (g);

-% MOT: percentage of dry matter content in the sample.

Total organic carbon was determined according to the formula of below:

$$\% C = \frac{(\% MOT)}{2}$$

**The total organic nitrogen**

The total organic nitrogen content was determined by the Kjeldahl method. The mineralized sample was distilled with 40% sodium hydroxide in a BUCHI K-350 nitrogen distiller. The nitrogen vapours obtained was collected in an Erlenmeyer flask containing a pinkish color mixture composed of 20 ml of 3% boric acid and 3 drops of Tashiro reagent. This mixture gradually turns yellowish-green in the case where the distilled sample contains nitrogen, as the sample drops from the distillation column was added. The solution obtained was assayed by titrimetry with 0.1 N sulfuric acid.

The C / N ratio of the composts was calculated from the organic carbon and nitrogen values obtained. It was determined according to the formula below:

$$C/N = \frac{percentage\ of\ organic\ carbon}{\text{percentage of total nitrogen}}$$

## II.3.11.3. Total fungal analysis

Total fungal analysis was carried out according to the suspensions-dilutions technique (Rapilly, 1968). On agar Potato dextrose agar (PDA) medium was added an antibiotic (chloramphenicol). In a 250 ml Erlenmeyer flask containing 90 ml of distilled water sterile, 10 g of dry soil was added aseptically (after drying at 30 °C overnight). This mixture was stirred mechanically with magnetic bars for 30 minutes to suspend the soil particles and the spores and mycelia attached thereto. The suspension obtained corresponds to the $10^{-1}$ dilution. 1 ml of the $10^{-1}$ dilution was removed aseptically and put in 9 ml of sterile distilled water thus giving the $10^{-2}$ dilution which was stirred for two minutes before taking 1 ml which has been added to 9 ml of water sterile distilled and so on until dilution $10^{-8}$. 0.1 ml was taken from each dilution, operating from $10^{-8}$ dilution to the $10^{-1}$ dilution, and seeded onto the culture media, using a sterile glass bent pipette. Petri dishes were incubated at 26 ° C for 3 days. The fungal load was determined by colony counting and the results were expressed in CFU (Colony Forming Units) / g of soil according to the mathematical formula below.

$$\boldsymbol{N = \frac{\Sigma\ \text{colonies}}{2\text{Vml x}(\text{n1} + 0.1\ \text{n2})}\ \text{x d1}}$$

N: Number of CFU per gram of compost; Σ colonies: Sum of colonies of interpretable petri dishes; V: Volume of solution deposited (1ml); n1: Number of petri dishes considered at the first dilution retained; n2: Number of petri dishes considered at the second dilution retained; d1: Factor of the first dilution retained. Only Petri dishes counting between 15 and 150 colonies at two successive dilutions were selected for enumeration (Dutruc-Rosset, 2003).

### II.3.11.4. Total bacterial analysis

The determination of the total bacterial flora was carried out according to the technic of suspensions-dilutions (Rapilly, 1968), on solid medium, nutrient agar added to an antifungal agent: 0.5% nystatin. 5 g of each soil was placed in a 100 ml Erlenmeyer flask containing 45 ml of sterile physiological saline (9 g of NaCl / L of distilled water) and suspended with a magnetic stirrer for 30 minutes. The suspension was then decanted for 20 minutes, then the supernatant was removed, and it constitutes the $10^{-1}$ dilution. From this suspension, decimal dilutions were made up to $10^{-8}$. 0.1 ml was taken from each dilution, operating from $10^{-1}$ dilution to $10^{-8}$ dilution, and seeded onto the culture media, using a sterile glass bent pipette. The petri dishes was incubated at 30 °C for 24 hours. The bacterial load was determined by colony counting and the results were expressed in CFU (Colony Forming Units) / g of soil according to the mathematical formula below.

$$N = \frac{\Sigma \text{ colonies}}{2V\text{ml} \times (n1 + 0.1\, n2)} \times d1$$

N: Number of CFU per gram of compost; Σ colonies: Sum of colonies of interpretable petri dishes; V: Volume of solution deposited (1ml); n1: Number of petri dishes considered at the first dilution retained; n2: Number of petri dishes considered at the second dilution retained; d1: Factor of the first dilution retained. Only Petri dishes counting between 15 and 150 colonies at two successive dilutions were selected for enumeration (Dutruc-Rosset, 2003).

### II.3.12 Statistical analysis

All the assays were carried out in triplicate. The results are expressed as mean values and standard error (SE) of the mean. The differences in between treatments were analysed using one-way analysis of variance (ANOVA) followed by Tukey's tests. For all analyses, p-values $P<0.05$ were considered statistically significant. Data were analysed using SPSS version 16 software.

# CHAPTER III: RESULTS AND DISCUSSION

# CHAPTER III: RESULTS AND DISCUSSION

## III.1 RESULTS

### III.1.1 Survey of the cultural practices and diseases management of sweet pepper at the locality of Foumbot, west region of Cameroon

#### III.1.1 .1 Characteristics of the Studied Famers

Figures: 23, 24, 25 and 26– below illustrate respectively information concerning women and men level of education, the percentage of men and women sweet pepper farmers, the ages of sweet pepper cultivators and their year of experience. Males represented 80% of the sampled population. Their level of education varies from primary school to University with the majority found between primary school (48%) and secondary school (30%). On the other hand, females represent 12 per cent of the sampled farmers and their level of education fluctuated from primary (6%) and secondary (6%) school. However, most sweet pepper farmers (80%) aged between 18 to 48 years old. The years of experience given by farmers vary from one to thirty years with 48% who have the greatest level of experience in between 10 to 30 years and 52% with the lowest level of experience varying from 1 to 10 years. Most of them produced sweet pepper for market and few produced for both the market and home consumption.

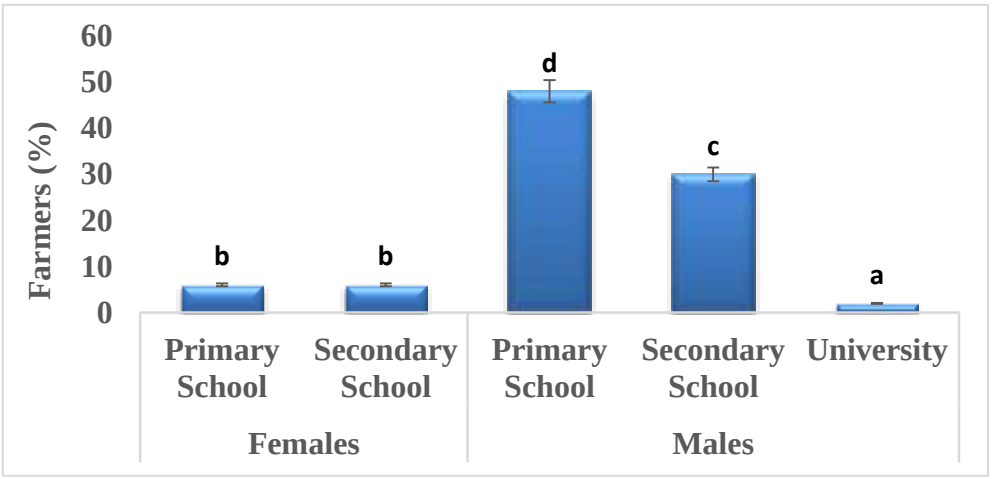



**Figure 23:** Sweet pepper farmers level of education according to sex (%)/ Bar charts with the same letter are not significantly different.

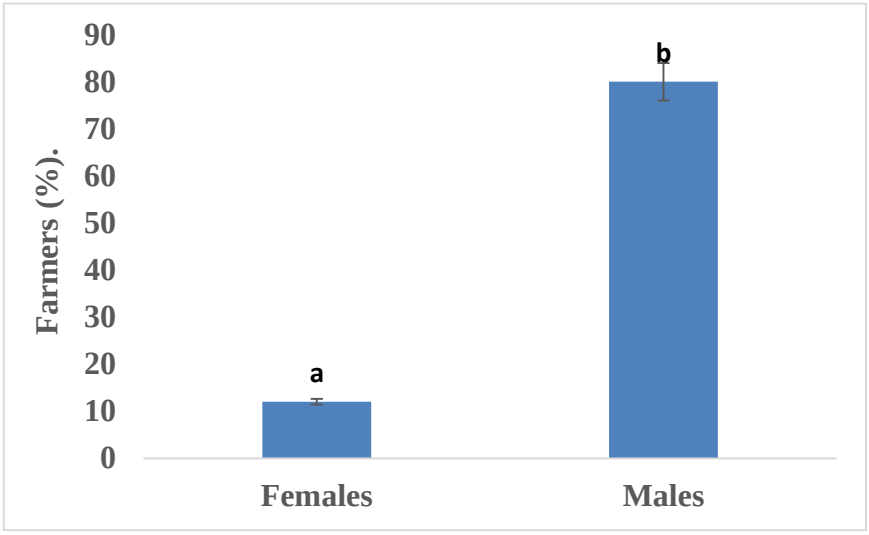



**Figure 24:** Percentage of men and women sweet pepper farmers/ Bar charts with the same letter are not significantly different.

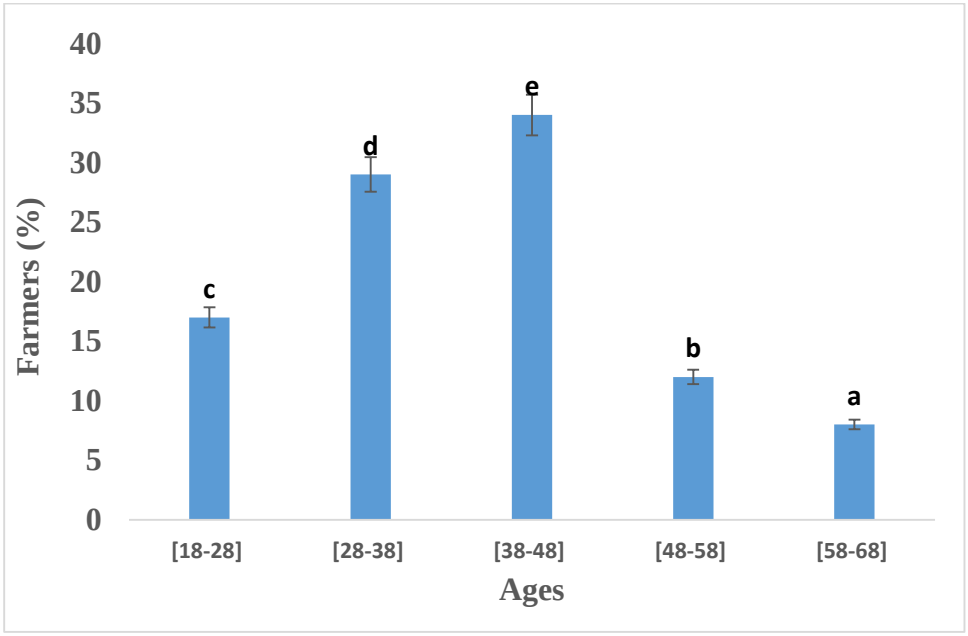



**Figure 25:** Varieties of sweet pepper farmers according to age's classes (%)/ Bar charts with the same letter are not significantly different.

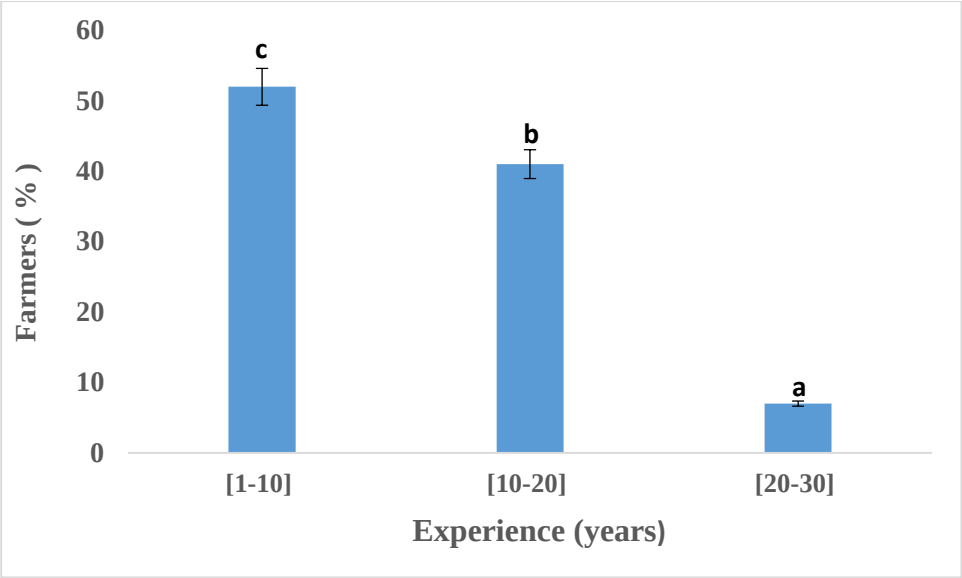



**Figure 26:** Varieties of sweet pepper farmers according to years of experience / Bar charts with the same letter are not significantly different.

### III.1.1.2 Sweet pepper seeds and other small tools used by farmers in the field

#### III.1.1.2.1 Varieties of sweet pepper seeds

The varieties of sweet pepper seeds cultivated in Foumbot by the sampled cultivators are Yolo wonder, Simba, Poivron vert Lamuyo F1. But Yolo wonder and Simba varieties were the most used. These varieties were provided by distributors of phytosanitary products.

#### III.1.1.2.2 Small tools used by sweet pepper farmers

Table 7 presents the small tools used by most of the sweet pepper farmers from the West Region of Cameroon (Foumbot Agricultural Area).

**Table 7:** Small tools used by sweet peppers farmers and their utilization

| Tools | Usage |
|---|---|
| Machete | Clearing Brush |
| Rakes | Smooth out beds and Collecting Leaves |
| hoe | Eliminate weeds |
| Shovels | Used respectively to dig large holes and transport heavier materials such as wet soil and cut the roots and sods as well as break up compacted soil. |
| Forks | Used for digging of soils in situations where the use of spade may be difficult for turning of soils, to till large areas of soil, break up compacted clods and rake out weeds. |
| Gloves | Used to protect hands and fingers from cuts, blisters, calluses, sun damages, abrasions and dirt. |
| Footwear | Used to protect feet from stones, falling items or tools |
| Wheelbarrow | Used for transportation of seedlings, planting materials, growing media as well as other small loads. |
| Meter | To measure the distance in between seedlings and rows |
| Watering can | It is used for watering seedbeds, nursery beds and potted plants to avoid washing off the soil and causing damage to young seedlings. |
| Hand Pressure Agricultural Sprayer | It is used for spraying insecticides, fungicides, herbicides, |
| Motopomp | To water sweet pepper plants |

### III.1.1.3 Sweet pepper cultivation

#### III.1.1.3.1 Field for sweet pepper cultivation

Most farmers (89 %) had a sweet pepper field with a surface area between 0.5 and 1 hectare while only a few farmers (7%) had sweet pepper field of about 2 hectares (figure 27). Men (35% and 38%) respectively grow sweet pepper in the area of 0.5 ha and 1ha and only 7 per cent of men use 2 ha. On the other hand, 8% of women out of 12% generally use 0.5 ha to cultivate sweet pepper.

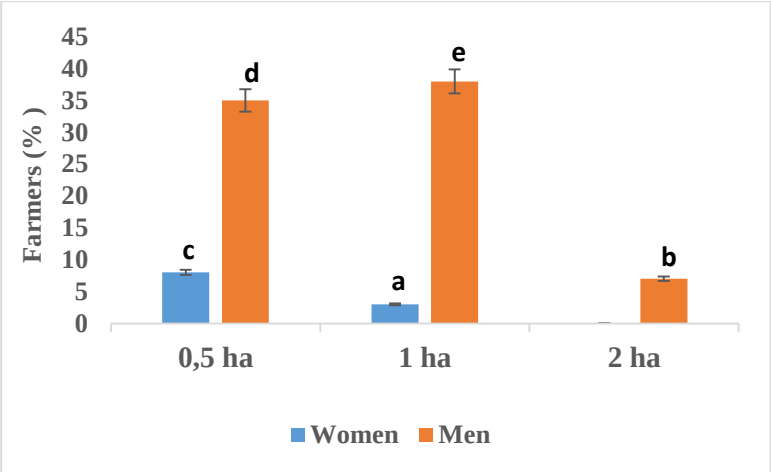



**Figure 27:** Farm size distribution used for sweet pepper production/ Bar charts with the same letter are not significantly different.

### III.1.1.3.2 Seedlings production and transplantation

80% of sweet pepper farmers who were interviewed from the West Region of Cameroon usually grow sweet pepper two times per year. 79 % grow the nursery on ridges and 21% of the remaining farmers on the seedbeds. The location of the nursery was generally either far from the site of transplantation or near depending on the availability of water. In west region of Cameroon, most of the farmers cultivate sweet pepper throughout the year. Those who are not able to get the motopomp or pumps to water plant from long distancings only grow sweet pepper during the raining season. However, seeds are not treated before being sown but only one week after sowing. Sweet pepper seeds are sown in nursery beds after enriching it with the mixture of cow dung and let it during one week. Usually, after one week of growth, the nursery is attacked by fungi, which always cause stems rot. The pesticides used to treat nursery by sweet pepper farmers in that region are respectively fungicide (Mancostar 80WP) and insecticides ( Mocap EC, Timik, Plantineb 80WP, Jumper and Ascot). The frequency of the nursery treatment was after one week or two, depending on each farmer, still the right time of seedlings transplantation. Seedlings are transplanted after a month and a half of growth. Farmers generally transplant seedlings on ridges, which are a mixture of the soil and cow dung. Then, after one week of transplantation farmers enrich the soil with chemical fertilizers such as NPK: 20.10.10, which is the most synthetic fertilizer used for sweet pepper cultivation, including NPK: 30.10.10, which is the most foliar fertilizer used. Generally, they fertilize the soil that surrounds one or two plants of sweet pepper with a handful hand of synthetic fertilizer. The

below table 8 presents the frequencies of soil amendment that are usually applied by the surveyed cultivators.

**Table 8:** Frequency of soil chemical fertilizers application

| **Frequencies** | **Sweet pepper farmers** |
|---|---|
| Three times | 3% |
| One week after transplanting | 2% |
| Three weeks after transplanting | 3% |
| After two weeks of transplanting and during the first flowering | 6% |
| Two weeks after transplanting and after each harvesting | 32% |
| After each 21days and each harvesting | 48% |
| Three times before harvesting and after two harvestings | 6% |

After the transplantation of sweet pepper seeds 13 percent of farmers usually sow other plants around or inside the sweet pepper farm such as beans, corn and cucumber.

### III.1.1.3.3 Water used for irrigation in sweet pepper farms and the choice of growing

The surface canals were the main means of water supply to the farms. Water used for irrigation by the sampled farmers in the Foumbot agricultural area has multiple origins such as water coming out of the mountains, streams, swamp and rainwater. Most sweet pepper farms are not located far from those origins of water. Besides, the main tools used by sweet peppers growers, who had larger surfaces (>0.25ha), to water sweet pepper plants are motopomp/pumps and watering can for those who had fewer surfaces. Generally, the majority of sweet pepper cultivators prefer growing sweet pepper during the rainy season and only a few of them prefer the dry season.

### III.1.1.3.4 Sweet pepper diseases and disease management

According to the respondents, sweet pepper diseases start appearing after one week of transplantation and they mainly attack either leaves, stems, and fruits or the whole plant depending on the type of diseases. To fight against those diseases the cultivators of sweet peppers always use the types of pesticides presented in table 10. Diseases usually caused more than 50 % yield losses, which reduces agricultural yields. 85% of the respondents were not able to identify sweet pepper pests and diseases. They did not have access to information about integrated pest management, pesticide use and safety, or insect and disease identification. The

vegetable growers depend on the experience of others for advice on managing pests and diseases.

However, The major symptoms described by the sweet pepper farmers at Foumbot were:

- Circular lesions on leaves and stems with dark margins,
- mosaic-like patches (mottling) on the leaves, curling of leaves and the yellowing of plant tissues.
- mosaic blight, ringspot, fruit woodiness and necrosis of fruit
- the formation of small, circular, water-soaked spots on leaves, stems, petioles,
- Yellowing of foliage and wilting upper leaves; wilting spread to all parts of a plant; leaves remain attached to plant and are dark green; red-brown discolouration of vascular tissue; plant death,
- yellow to brown discolouration of the upper leaf; edges of leaves; the dropping of leaves from a plant,
- plants becoming stunted and lower leaves turning yellow; as the infection progresses, more leaves turn yellow and begin dropping from the plant; plants wilt during the day and recover at night; wilting becomes permanent and plant death ensues.
- Black lesions on stems; wilting plant; circular grey-brown lesions on leaves; dark lesions on fruit,
- Small soft bodied insects on the underside of leaves and/or stems of a plant; usually green or yellow in colour, yellow leaves and distorted, necrotic spots on leaves and/or stunted shoots.

**III.1.1.3.5 Pesticides used by farmer to cultivate sweet pepper**

About 85% of farmers interviewed used synthetic pesticides. The reasons provided by the 15% not using pesticides were high prices, especially for small-scale farmers who do not produce a lot of sweet peppers. Pesticides used include fungicides, herbicides and insecticides. The characteristics of synthetic pesticides used are presented in Table 9. Respectively 10 insecticides, 07 fungicides and 05 herbicides were used by sampled farmers as pesticides. Among the class of insecticides, cypermethrin represents 63% of active ingredients compared to lamda-cyalothrin, Aldicarb and others. On the other hand, Mancozeb represents 85% of active ingredients, among the class of fungicide, compared to Maneb. The toxicity of those pesticides varied from class II (moderately toxic) to class III (slightly hazardous). Most of the sampled farmers abundantly use two fungicides (maneb and mancozeb) that are used in all

combinations (100%), which are all classified as slightly hazardous substances according to WHO (1965 ; 2004) toxicity classification. Concerning herbicides utilization, only three were reported, to be used by the farmers who were sampled, among which glyphosate (the first) is used at 50% followed by paraquat at 37% (the second) and 2.4- D 23%. For all pesticides, users can vary the type of mixtures but the contents remain the same with changes in concentration. However, the frequency of spraying those pesticides (fungicides and insecticides), by the sampled farmers, to treat sweet pepper diseases was after each week depending on the degree of the disease. Also, while spraying pesticides, the whole sweet pepper plant is treated instead of one part such as leaves stems and fruit. Herbicides can be used two or three times per crop cycle or for a different field.

**Table 9:** Types of pesticides and herbicides used by the cultivators of sweet pepper.

| Class | Commercial names | Active ingredient | Toxicity class |
|---|---|---|---|
| Insecticide | Cypercal 50 EC | Cypermethrin | II |
| | Cigogne 50 EC | Cypermethrin | II |
| | Plantineb 80WP | Mabeb | III |
| | Cyperplant 100 EC | Cypermethrin | II |
| | Cytrine 25 EC | Cypermethrin | II |
| | Ascot | Lambda-cyhalothrine | II |
| | Fix 50 | | II |
| | Timik | Aldicarb | |
| | K-Optimal | Lambda-cyhalothrine + Acétamipride | II |
| | Mocap EC | Ethoprop | |
| Fungicides | Mancoxy plus 720 WP | Metalaxyl + Mancozeb | III |
| | Cleanzeb Blue 80WP | Mancozeb | III |
| | Penncozeb 80WP | Mancozeb | III |
| | Fongistar 72%WP | Metalaxyl + Mancozeb | III |
| | Mancostar 80WP | Mancozeb | III |
| | Manco 80WP | Mancozeb | III |
| | Trimangol 80WP | Maneb | III |
| herbicides | Roundup | Glyphosate | III |
| | Suprazone Royal | Paraquat | II |
| | Amistar 720 SL | 2,4-D Sel Amide | III |
| | Casse-tout | Glyphosate | III |

### III.1.1.3.6 The phonological periode of pesticide application

The stage of pesticide application varied with sweet pepper growth stages (Figure 28). The majority of the cultivators of sweet pepper could not say what time of plant growth was most effective for controlling pests. That is the reason why 46 % of the sampled farmers said that they prefer spray pesticides in all stages. However, a weekly pesticide spraying was the most common, with most of the sampled farmers spraying insecticide and fungicides, respectively. 44% of sweet pepper farmers did not take note of the number of times they applied chemicals pesticides on their crops.

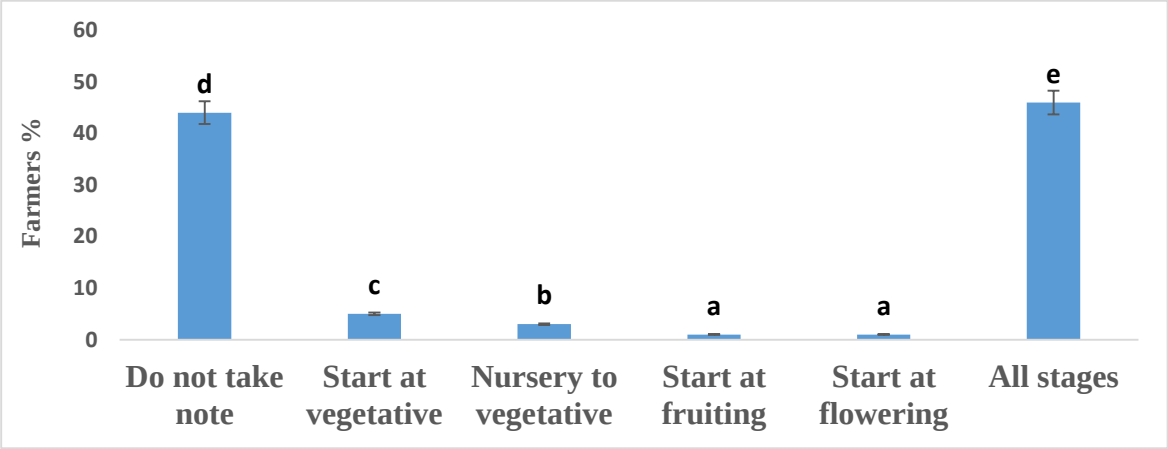



**Figure 28:** Proportion of sweet papper farmers applying pesticide at different phenological periods/ Bar charts with the same letter are not significantly different.

### III.1.1.3.7 The harvesting period and yield of sweet pepper fruits

86 percent of the sampled farmers harvest 0.5 to 20 tons of sweet pepper fruit per farm. Only 5 percent and 3 percent respectively harvest 20 to 50 tons and 50 to 100 tons of sweet pepper fruit per farm. (Figure: 29). However, most of them harvest more than three times. They usually harvest fruit after one to seven days of the last spraying of pesticides and most farmers do not use synthetic products to extend the period of sweet pepper fruit conservation. Besides, after harvesting, the period of the conservation of sweet pepper fruit vary in between seven to fifteen days.

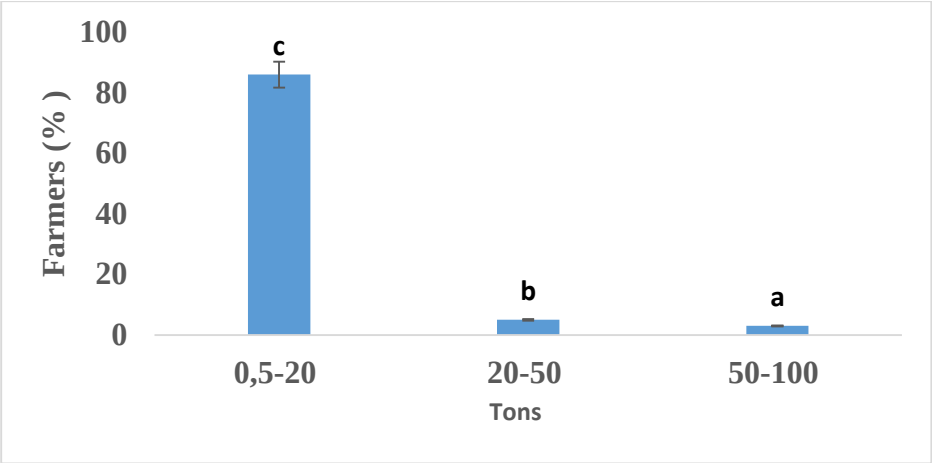



**Figure 29:** Yield of sweet pepper produced by the sampled cultivators. Bar charts with the same letter are not significantly different.

### III.1.2 Composting

#### III .1.2.1 Figures of the produced composts

The composting of the below different treatments lasted 3 months. The produced composts (C1, C2, C3, and C4) were odourless during the composting process and presented the same odour (they did not have a smell of ammonia) at the end of composting. They had a dark brown color, relatively dry and uniform structure and its texture was similar to the soil's texture. Their temperature was 25 ° C. Figure 30 below presents the obtained composts.

**C1**

**C2**

**C3**

**C4**

**Figure 30:** Composts produced from the different weights of cassava peels. (Onguene. *et al.*, 2021)

### III.1.2.2 Material characteristics

The physical, chemical properties and the micronutrients content of the Cassava peels are reported in Table 10.

**Table 10:** Physical and chemical properties of cassava peels

| Parameters | cassava peel |
|---|---|
| pH | 5.7 |
| Organic carbon | 44.3% |
| Total nitrogen | 1.47% |
| Total phosphorus | 7.9g/kg |
| Total potassium | 1.1g/kg |
| total calcium | 18.9g/kg |
| Total magnesium | 8.1g/kg |
| total sodium | 0.12g/kg |
| Moisture | 2.43% |
| C/N | 30.13 |

Values are means ± standard deviations of 3 repetitions.

### III.1.2.3 Physical and chemical properties

The physical and chemical properties and the micronutrients content of the produced composts are reported in Table 11 and 12.

At the end of the composting, the pH of C1, C2, C3 and C4 was in between 6.50 to 6.73, which slightly increased compared to the pH (5.7) of cassava peels. There was no significant difference between the pH of the obtained composts. The total nitrogen (2.68%) of the first compost (C1) was not significantly higher than the total nitrogen of the initial subtracts. Also, the total nitrogen (respectively 5.30%, 8.1%, and 10.50%) of the last three compost significantly increased at the end of the process. The same fashion is reflected concerning the percentage of the organic carbon, in which the organic carbon of C2 (70.5%), C3 (105.75%) and C4 (141%) dramatically increased. There was respectively a significant difference

between the percentage of organic carbon of cassava peels (44.3%), C1 (35.25%), and the last three compost (C2, C3 and C4).

On the other hand, the proportion of the total potassium of each produced composts increased significantly and was respectively 5.63 mg.kg-1, 11.25 mg.kg-1, 16.23 mg.kg-1, and 22.49 mg.kg-1; while the percentage of the total phosphorus of the each produced compost, which was respectively C1 (130 mg.kg-1), C2 (240 mg.kg-1), C3 (380 mg.kg-1), and C4 (500), gradually decreased with the increase among of cassava peels. The ratio C/N Of the four cassava peels manure has significantly decreased. The value of those ratios was between 13.15 and 13.4, and there was not a great difference in between the ratio C/N of the produced composts.

**Table 11:** pH, C, N, P, K and C/N of the produced composts made with increasing Kg of cassava peel.

| composts | Parameters | | | | | |
|---|---|---|---|---|---|---|
| | pH | Total nitrogen (%) | Total phosphorus ($mg.kg^{-1}$) | Total potassium ($mg.kg^{-1}$) | Organic carbon (%) | C/N |
| C1 | $6.50\pm0.12^{a}$ | $2.68 \pm 0.34^{a}$ | $130 \pm 0.09^{a}$ | $5.63 \pm 1.34^{a}$ | $35.25 \pm 2.62^{a}$ | $13.15^{a}$ |
| C2 | $6.61\pm0.20^{a}$ | $5.30 \pm 0.99^{a}$ | $240 \pm 0.16^{b}$ | $11.25 \pm 2.67^{b}$ | $70.5 \pm 4.24^{b}$ | $13.30^{a}$ |
| C3 | $6.68\pm0.14^{a}$ | $8.01 \pm 0.03^{a}$ | $380 \pm 0.26^{c}$ | $16.23 \pm 3.85^{b}$ | $105.75 \pm 3.86^{c}$ | $13.20^{a}$ |
| C4 | $6.73\pm0.11^{a}$ | $10.50 \pm 0.05^{a}$ | $500 \pm 0.20^{d}$ | $22.49 \pm 5.33^{b}$ | $141 \pm 5.48^{d}$ | $13.42^{a}$ |

Means±SD followed by the same letter in a column are not significantly different at $P \leq 0.05$

However, the EC slightly increased with the among of cassava peels that was composted and the difference was not significant. The concentration of Mg, Ca, K, Na, and Cu gradually increased with the increase among of cassava peels. The concentration of the four composts in terms of Mn and Zn was repectively in between 0, 10 to 0, 14g.kg-1 and 0,028 to 0, 03g.kg-1.(Table 12).

**Table 12:** EC, extractable nutrients and heavy metal content of the produced composts made with increasing Kg of cassava peel.

| composts | Parameters | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | EC ($\mu S.cm^{-1}$) | Mg (mg.kg-1) | Ca (mg.kg-1) | K (mg.kg-1) | Na (mg.kg-1) | Mn (g.kg-1) | Cu (g.kg-1) | Zin (g.kg-1) |
| C1 | 1499±210.86 [a] | 0.04±0.01 [a] | 0.24±0.12 [a] | 5.63±1.23 [a] | 2.38±0.50[a] | 0,10 ± 1,11[a] | 5.53±1.16[a] | 0,028 ± 0,01[a] |
| C2 | 1737±211.70 [a] | 0.07±0.03 [a] | 0.48±0.19 [a] | 11.26±1.30 [a] | 3.58±0.29[a] | 0,11 ± 1,01[a] | 8.20±0.30[a] | 0,026 ± 0,014[a] |
| C3 | 1830±187.74 [a] | 0.11±0.04 [a] | 0.73±0.23 [a] | 16.80±2.01 [a] | 7.58±2.21[b] | 0,12 ± 1,21[a] | 12.56±0.23[a] | 0,025 ± 0,011[a] |
| C4 | 1924±199.84 [a] | 0.15±0.02 [a] | 0.94±0.29 [a] | 22.49±0.54 [b] | 8.59±0.40[b] | 0,14 ± 1,15[a] | 20.32±2.35[b] | 0,03 ± 0,012[a] |

Means±SD followed by the same letter in a column are not significantly different at $P \leq 0.05$

### III.1.2.4 Phytotoxicity

#### III.1.2.4.1 Germination Index (GI)

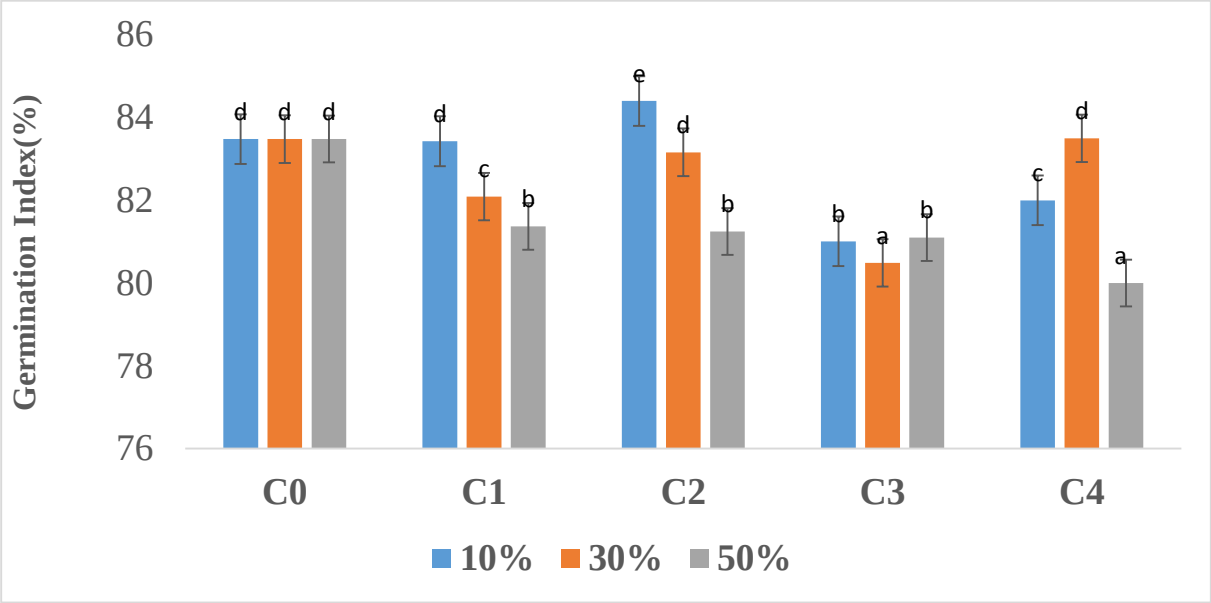



**Figure 31:** Variation of germination indexes of sweet pepper seeds growing on different cassava peels-based composts extracts. Bar charts with the same letter are not significantly different at at 5% level.

The above figure 31 shows that cassava peels-based composts were not toxic to the sweet pepper seeds and seedlings at the concentration of 10% 30% and 50%. All extracts, C1, C2, C3, and C4, had a germination index between 80% to 84.4%, and the differences were significantly different.

#### III.1.2.4.2 Emergence test

**Table 13:** The percentage emergence of sweet peppers seeds

| Samples of the composts | The rate of germination (%) |
|---|---|
| B1 | $97 \pm 4.20^{a}$ |
| B2 | $96 \pm 4.81^{a}$ |
| B3 | $98 \pm 4.74^{a}$ |
| B4 | $97 \pm 4.90^{a}$ |

Means±SD followed by the same letter in a column are not significantly different at $P \leq 0.05$

Table 13 illustrated and confirmed that all the samples of the composts were not toxic to the sweet pepper seeds and seedlings respectively at the proportion of 1kg, 2kg, 4kg, and 6kg, which had the rate of germination in between 96.20 and 98.40 %.

### III.1.2.5 Biological properties

The increased of the amount of cassava peels did not negatively impair the concentration of fungal and bacterial population. There was not a significant difference respectively in between the concentration of bacterial and fungal biomass from C1, C2, C3, and C4 (Table 14). However, the proportion of fungal biomass was higher than the proportion of bacterial, which was respectively in between 88.2 to 89.3 for fungi population and 71.9 to 74.1 for the bacterial population.

**Table 14**: Microbial biomass counted in compost samples.

| Treatment | Microbial biomass ($10^5$ u.f.c.g-1 compost) | |
|---|---|---|
| | **Fungi** | **Bacteria** |
| **C1** | $88.6 \pm 1.49^a$ | $71.9 \pm 6.27^a$ |
| **C2** | $89.1 \pm 6.41^a$ | $72.4 \pm 0.15^a$ |
| **C3** | $88.9 \pm 0.75^a$ | $72.9 \pm 5.50^a$ |
| **C4** | $89.3 \pm 7.42^a$ | $74.1 \pm 1.04^b$ |

Means±SD followed by the same letter in a column are not significantly different at $P \leq 0.05$

### III.1.3 Production of sweet pepper in pot and field experiments

### III.1.3.1 Soil properties

**Table 15: Soil properties of the experimental site: pot and field experiments**

| parameters | pH | EC ($\mu S.cm^{-1}$) | Organic carbon (%) | Total N (%) | C/N ratio | P (g.kg-1) | K (mg.kg-1) | Na (mg.kg-1) | Mg (mg.kg-1) | Ca (mg.kg-1) | Cu (g.kg-1) | Fe (g.kg-1) | Mn (g.kg-1) | Zn (g.kg-1) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **soil** | 6.5±0.5 | 76.7±0.74 | 5.53±0.32 | 0.18±1.15 | 30.7±0.9 | 0.058±0.2 | 4.24±0.3 | 1.42±0.1 | 0.01±0.9 | 0.03±0.4 | 0.72±2.3 | 83.1±0.8 | 0.52±0.3 | 0.01±0.2 |

Values are means ± standard deviations of 3 repetitions.

### III.1.3.2 Vegetative growth characteristics

Table 16 shows that, sweet pepper plants cultivated with the soil amended with cassava peels compost and sprayed respectively with aqueous extract of *ocimum grastissimum* leave, had the plant height, number of leaves and crown diameter significantly higher than the sweet pepper plants grown from the soil amended with the NPK-B, NPK-E and NPK-S, as well as from the soil without any amendement. CP1-B and CP2-B had the highest plant height (field experiment: CP1-B= 15.3cm ; CP2-B=15.57cm and pot experiment: CP1-B= 14.53cm ; CP2-B=14.65cm), the number of leaves ( field experiment: CP1-B=15.6; CP2-B=15.66 and pot experiment: CP1-B=15.33 ; CP2-B=15.11) and the crown diameter (field experiment: CP1-B=0.28cm ; CP2-B=0.31cm and pot experiment: CP1-B=0.25cm ; CP2-B=0.29cm) than those cultivated with chemical fertilizers and treated with mancozeb/K-optimal, which had respectively from the field experiment ( plant height : NPK-S= 12.24 ; number of leaves : NPK-S=15 and crown diameter : NPK-S= 0.21) and pot experiment ( plant height : NPK-S=13.62cm ; number of leaves : NPK-S= 14.33 and crown diameter : NPK-S=0.2cm ). In addition, the plant height, the number of leaves and the crown diameter of the plants grew from the soil amended with the compost and spraid with water were also significantly higher than the plants cultivated with inorganic fertilizers and spraid with water, which accounted respectively under field experiment (plant height : CP1-E=14.6 ; CP2-

E=14.21cm ; NPK-E=10.53cm ; number of leaves : CP1-E=14 ; CP2-E= 14.33 ; NPK-E= 10.53 and crown diameter : CP1-E=0.29cm ; CP2-E=0.28cm ; NPK-E=0.18) and in pot experiment ( plant height : CP1-E= 13.33 cm; CP2-E=14.56 ; NPK-E=10.56cm ; number of leaves : CP1-E=14.66 ; CP2-E=14.33 ; NPK-E=13.33 and the crown diameter : CP1-E=0.23cm ; CP2-E=0.23cm ; NPK-E=0.19cm).

**Table 16:** Effect of treatments on plant height, the number of leaves and the crown diameter of sweet pepper plants after two weeks of transplantation

| | Field experiment | | | Pot experiment | | |
|---|---|---|---|---|---|---|
| **T** | **Plant height (cm)** | **Number of Leaves per Plant** | **Crown diameter per plant(cm)** | **Plant height (cm)** | **Number of Leaves per Plant** | **Crown diameter per plant(mm)** |
| **CP1-B** | $15.3\pm0.26^{a}$ | $15.6\pm0.57^{a}$ | $0.28\pm0.02^{b}$ | $14.53\pm0.15^{b}$ | $15.33\pm0.57^{a}$ | $0.25\pm0.005^{b}$ |
| **CP1-E** | $14.6\pm0.33^{b}$ | $14\pm0^{b}$ | $0.29\pm0.01^{b}$ | $13.33\pm0.01^{b}$ | $14.66\pm0.57^{b}$ | $0.23\pm0.01^{c}$ |
| **CP1-S** | $14.15\pm0.05^{b}$ | $12\pm1.73^{c}$ | $0.28\pm0.005^{b}$ | $15.6\pm0.02^{a}$ | $12.33\pm1.52^{d}$ | $0.26\pm0.13^{b}$ |
| **CP2-B** | $15.57\pm0.06^{a}$ | $15.66\pm1.15^{a}$ | $0.31\pm0.01^{a}$ | $14.65\pm0.01^{a}$ | $15.11\pm0.57^{c}$ | $0.29\pm0^{a}$ |
| **CP2-E** | $14.21\pm0.22^{b}$ | $14.33\pm2.08^{b}$ | $0.28\pm0.005^{b}$ | 14.56±0.36c | $14.33\pm0.57^{b}$ | $0.23\pm0.005^{c}$ |
| **CP2-S** | $14.36\pm0.05^{b}$ | $15.66\pm8.44^{a}$ | $0.28\pm0.01^{b}$ | $14.6\pm0.45^{a}$ | $14.66\pm0.57^{b}$ | $0.25\pm0.01^{b}$ |
| **NPK-B** | $12.8\pm0.2^{c}$ | $15.33\pm0.57^{a}$ | $0.21\pm0.02^{c}$ | $14.06\pm0.12^{a}$ | $14.33\pm0.57^{a}$ | $0.2\pm3.39^{d}$ |
| **NPK-E** | $10.53\pm0.75^{c}$ | $12.33\pm0.57^{b}$ | $0.18\pm0.01^{d}$ | 10.56±0.81c | $13.33\pm0.57^{c}$ | $0.19\pm0.01^{d}$ |
| **NPK-S** | $12.24\pm0.72^{c}$ | $15\pm0^{a}$ | $0.21\pm0.03^{c}$ | 13.62±0.46c | $14.33\pm0.57^{b}$ | $0.2\pm3.39^{d}$ |
| **C-B** | $6.5\pm0.1^{d}$ | $5\pm0^{d}$ | $0.10\pm0.005^{e}$ | $6.2\pm0.26^{d}$ | $6.66\pm0.57^{e}$ | $0.1\pm1.69^{e}$ |
| **C-E** | $6.3\pm0.2^{d}$ | $4\pm0^{d}$ | $0.11\pm0.015^{e}$ | $4.1\pm0.1^{e}$ | $4.66\pm0.57^{c}$ | $0.1\pm1.69^{e}$ |
| **C-S** | $6.3\pm0.1^{d}$ | $5.6\pm0.57^{e}$ | $0.10\pm0.005^{e}$ | $6.21\pm0.01^{d}$ | $5.93\pm0.57^{e}$ | $0.1\pm1.69^{e}$ |

Means±SD followed by the same letter in a column are not significantly different at $P < 0.05$

Table 17 illustrates that, after four weeks of transplantation, the plant height, the number of leaves and crown diameter of the plants cultivated both in pot and field experiment with the produced compost and spraid with aqueouse extract of *Ocimum grastissimum* leaves, were significantly higher than those cultivated with NPK-B, NPK-E and NPK-S. In addition, the plant height increased with the increasing amount of cassava peels compost both under pot experiment (CP1-B= 19.14 cm ; CP1-E=19.4cm, CP1-S=19.8cm, CP2-B=20.9cm ; CP2-E=20.3cm and CP2-S=20.7cm) and field experiment (CP1-B=19.02cm ; CP1-E=18.08cm ; CP1-S= 20.04cm, CP2-B= 22.63cm ; CP2-E= 20.3cm and CP2-S=22.3cm).

**Table 17:** Effect of treatments on plant height, the number of leaves and the crown diameter of sweet pepper plants after four weeks of transplantation

| | Field experiment | | | Pot experiment (2A) | | |
|---|---|---|---|---|---|---|
| **T** | **Plant height (cm)** | **Number of Leaves per Plant** | **Crown diameter per plant(cm)** | **Plant height (cm)** | **Number of Leaves per Plant** | **Crown diameter per plant(mm)** |
| **CP1-B** | $19.02\pm0.01^{b}$ | $25.7\pm5.19^{b}$ | $0.65\pm0.01^{a}$ | $19.4\pm3.6^{b}$ | $23.3\pm3.56^{a}$ | $0.5\pm1.18^{a}$ |
| **CP1-E** | $18.08\pm0.15^{c}$ | $20.9\pm1^{c}$ | $0.59\pm0.005^{a}$ | $18.4\pm0.85^{c}$ | $21.8\pm0.52^{b}$ | $0.5\pm0.41^{a}$ |
| **CP1-S** | $20.04\pm0.05^{b}$ | $25.53\pm0.57^{b}$ | $0.63\pm0.01^{a}$ | $19.8\pm1.54^{b}$ | $22.1\pm0.09^{b}$ | $0.5\pm0.40^{a}$ |
| **CP2-B** | $22.63\pm0.02^{a}$ | $27\pm1^{a}$ | $0.68\pm0.01^{a}$ | $20.9\pm0.01^{a}$ | $23.6.3\pm0.85^{a}$ | $0.6\pm0.01^{b}$ |
| **CP2-E** | $20.3\pm0.1^{b}$ | $20.8\pm1^{c}$ | $0.6\pm0.01^{a}$ | $20.3\pm0.05^{a}$ | $22.4\pm5.17^{b}$ | $0.6\pm1.70^{b}$ |
| **CP2-S** | $22.3\pm0.14^{a}$ | $26.2\pm0.57^{b}$ | $0.63\pm1.35^{a}$ | $20.7\pm6.74^{a}$ | $23.6\pm5.96^{a}$ | $0.59\pm1.46^{b}$ |
| **NPK-B** | $19.9\pm0.1^{b}$ | $20.66\pm0.57^{c}$ | $0.58\pm0.05^{b}$ | $18.5\pm0.91^{c}$ | $20.9\pm3.20^{c}$ | $0.55\pm1.67^{c}$ |
| **NPK-E** | $18.2\pm0.17^{C}$ | $19.6\pm0.57^{d}$ | $0.53\pm0.04^{b}$ | $18.9\pm1.54^{c}$ | $19.9\pm0.02^{c}$ | $0.5\pm0.54^{c}$ |
| **NPK-S** | $18.4\pm0.05^{C}$ | $21.3\pm0.15^{c}$ | $0.5\pm0.13^{b}$ | $18.9\pm0.45^{c}$ | $20.4\pm0.6^{c}$ | $0.5\pm0.15^{c}$ |
| **C-B** | $10.3\pm0.20^{e}$ | $7.3\pm0.04^{e}$ | $0.2\pm0.1^{c}$ | $9.12\pm0.82^{d}$ | $10.4\pm0.4^{d}$ | $0.19\pm0.02^{d}$ |
| **C-E** | $8.2\pm0.31^{f}$ | $4.12\pm0.05^{f}$ | $0.2\pm0.3^{c}$ | $9.30\pm46.3^{d}$ | $10.8\pm0.2^{d}$ | $0.2\pm0.3^{d}$ |
| **C-S** | $10.5\pm4.23^{e}$ | $6.9\pm0.45^{e}$ | $0.2\pm0.12^{c}$ | $8.9\pm0.01^{d}$ | $9.6\pm0.03^{d}$ | $0.2\pm0.14^{d}$ |

Means±SD followed by the same letter in a column are not significantly different at $P < 0.05$

According to the table 18, after six weeks of transplantation, the plant height, number of leaves and crown diameter of the sweet pepper plants grown with CP1-B and CP2-B plots sgnificantly increased than those from the soils amended with NPK-S plots and treated with mancozeb and k-optimal. Plants from CP1-B, CP2-B and NPK-S accounted respectively in pot experiment: plant height (CP1-B= 28.3cm; CP2-B=28.5cm; NPK-S=25.7cm); the number of leaves (CP1-B=30.5. CP2-B=31.1 and NPK-S=26.1) ; the crown diameter : (CP1-B=0.79 cm ; CP2-B=0.79 cm ; NPK-S=0.6 cm) and field experiment: plant height (CP1-B=30.1 cm ; CP2-B=31.1 cm ; NPK-S= 26.9cm) ; the number of leaves (CP1-B=38.8 ; CP2-B=39.3 and NPK-S=27.6) ; the crown diameter : ( CP1-B=0.87cm ; CP2-B=0.82cm ; NPK-S= 0.74cm). The number of leaves of plants counted from CP1-E and CP2-E was higher than the number of leaves counted from the plants grew with NPK-E both in pot (CP1-E=29.6 : CP2-E=29.9 and NPK-E=19.6) and field experiment (CP1-E=29.2: CP2-E=29.1 and NPK-E=19.9 ).

**Table 18:** Effect of treatments on plant height, the number of leaves and the crown diameter of sweet pepper Plants after six weeks of transplantation

| | Field experiment | | | Pot experiment | | |
|---|---|---|---|---|---|---|
| T | **Plant height (cm)** | **Number of Leaves per Plant** | **Crown diameter per plant(cm)** | **Plant height (cm)** | **Number of Leaves per Plant** | **Crown diameter per plant(mm)** |
| **CP1-B** | 30.1±0.2[a] | 38.8 ± 0.62[a] | 0.87±0.01[a] | 28.9±2.05[a] | 30.5±1.11[a] | 0.79±0.02[a] |
| **CP1-E** | 29.9±2.54[a] | 29.2±2.36[c] | 0.85±0.05[a] | 27.5±2.05b | 29.8±1.45[a] | 0.7±0.02[a] |
| **CP1-S** | 30.51±0.07[a] | 33±2.14[b] | 0.86±0.07[a] | 29.1±0.57[a] | 30.2±1.25[a] | 0.75±0.02[a] |
| **CP2-B** | 31.1±0.5[a] | 39.3±0.09[a] | 0.87±8.45[a] | 29.4±0.06[a] | 31.1±0.24[a] | 0.79±0.02[a] |
| **CP2-E** | 30.5±30.1[a] | 29.1.±1.8[c] | 0.83±1.05[a] | 27.5±45.3[b] | 29.9±1.87[a] | 0.74±0.02[a] |
| **CP2-S** | 30.4±0.06[a] | 32.92±0.5[b] | 0.86±1.06[a] | 27.8±4.23[b] | 29.8±0.71[a] | 0.78±0.02[a] |
| **NPK-B** | 26.3±0.01[b] | 29.6±0.08[c] | 0.71±0.68[b] | 24.8±0.01[b] | 25.8±4.16[b] | 0.6±0.02[b] |
| **NPK-E** | 26.6±25.6[b] | 22.3±4.52[e] | 0.71±0.58[b] | 24.9±0.05[b] | 24.4±1.22[c] | 0.6±0.02[b] |
| **NPK-S** | 26.9±20.7[b] | 27.4±0.9[d] | 0.74±0.7[b] | 25.7±0.05[b] | 26.1±2.36[b] | 0.6±0.02[b] |

Means±SD followed by the same letter in a column are not significantly different at $P < 0.05$

Table 19 illustrates that the utilization of cassava peels compost and aqueous extract of *Ocimum Grastissimum* significantly increased the the plant height, the number of leaves and the crown diameter of sweet pepper plants in comparison with the same parameters observed from the plants cultivated both with inorganic fertilizers and spraid with pesticides (mancozeb and K-optimal). The plant height, the number of leaves and crown diamete of the both types of plants were respectively in pot experiment (plant height : CP1-B=30.6cm ; CP2-B=33.5cm and NPK-S=29.9cm ; number of leaves : CP1-B= 38.6 ; CP2-B= 40 and NPK-S= 30.9 and crown diameter : CP1-B= 0.85cm ; CP2-B=0.85 cm and NPK-S=0.74cm) and field experiment (plant height : CP1-B=37.2cm ; CP2-B=37.4cm and NPK-S=29.9 cm ; number of leaves : CP1-B= 54.1 ; CP2-B= 55.4 and NPK-S= 41.3 and crown diameter : CP1-B=0 .9cm ; CP2-B= 0.9 cm and NPK-S=0.89).

**Table 19**: Effect of treatments on plant height, the number of leaves and the crown diameter of sweet pepper plants after eight weeks of transplantation

| | Field experiment | | | Pot experiment | | |
|---|---|---|---|---|---|---|
| T | Plant height (cm) | Number of Leaves per Plant | Crown diameter per plant (cm) | Plant height (cm) | Number of Leaves per Plant | Crown diameter per plant (mm) |
| **CP1-B** | 37.2±0.05[a] | 54.1±5.50[a] | 0.98±0.01[a] | 30.6±0.50[a] | 38.6±0.78[b] | 0.85±1.4[a] |
| **CP1-E** | 30.1±0.23[b] | 35.4±0.61[d] | 0.95±0.01[a] | 31.3±0.31[a] | 38.1±0.34[b] | 0.85±0.15[a] |
| **CP1-S** | 36.1±0.04[a] | 53.6±5.45[a] | 0.89±0.24[a] | 32.5±1.25[a] | 38.1±2.05[b] | 0.8±0.10[a] |
| **CP2-B** | 37.4±0.76[a] | 55.4±4.20[a] | 0.98±1.12[a] | 33.5±1.02[a] | 40±3.09[a] | 0.85±35.1[a] |
| **CP2-E** | 30.3±0.52[b] | 35.7±0.05[d] | 0.95±2.54[a] | 31.6±2.34[a] | 40.1±0.05[a] | 0.87±36.4[a] |
| **CP2-S** | 37.2±0.46[a] | 50.2±2.54[b] | 0.89±0.35[a] | 31.3±1.23[a] | 39.6±0.5[a] | 0.8±0.2[a] |
| **NPK-B** | 29.7±0.76[c] | 39.9±1.17[c] | 0.8±0.05[b] | 29.9±0.05[b] | 30.8±1.15[b] | 0.78±0.29[c] |
| **NPK-E** | 29.8±0.82[c] | 29.6±4.56[e] | 0.8±0.04[b] | 28.9.9±0.9[b] | 29.9±3.64[b] | 0.79±0.48[c] |
| **NPK-S** | 29.9±0.61[c] | 41.3±0.87[c] | 0.89±0.04[b] | 30.1±0.7[b] | 30.9±0.08[b] | 0.74±0.2[c] |

Means±SD followed by the same letter in a column are not significantly different at $P < 0.05$

In general, all the treatments CP1-B, CP1-E, CP1-S, CP2-B, CP2-E and CP2-S had sweet pepper plants with the highest number of branches which was significantly higher than the number of branhes of the treatments NPK-B, NPK-E and NPK-S (table 23). CP1-B and CP2-B stimulated the plants to get more branches, which were significantly higher than the number of branches from the treatment NPK-S both in field experiment: (CP1-B=5.1 ; CP2-B=5.6 and NPK-S=3.9) and pot experiment (CP1-B=3.66 ; CP2-B=3.66 and NPK-S=2.33). NPK-B, NPK-E and NPK-S on the other hand had sweet pepper plants with the Day of 50 percent floworing significantly higher than CP1-B, CP1-E, CP1-S, CP2-B, CP2-E and CP2-S. The maximum days (in pot and field experiments: 26 days) of 50 % flowering were recorded respectively with NPK-B, NPK-E and NPK-S while the minimum days (in pot and field experiments: 23 days) of 50 % flowering were recorded respectively by CP1-B and CP2-B (table 20).

**Table 20: Effect of treatments on the number of branches and the Day of 50 percent floworing**

| | Field experiment | | Pot experiment | |
|---|---|---|---|---|
| **T** | **The number of branches per plant** | **Day of 50 percent floworing** | **The number of branches per plant** | **Day of 50 percent floworing** |
| **CP1-B** | 5.1±0.57$^{a}$ | 23.66± 0.74$^{c}$ | 3.66±0.57$^{a}$ | 23.33±0.01$^{c}$ |
| **CP1-E** | 3.6±0.57$^{b}$ | 24.56±0.54$^{b}$ | 3.66±0.57$^{a}$ | 24.66±0.58$^{b}$ |
| **CP1-S** | 4.3±0.57$^{b}$ | 24.67±0.58$^{b}$ | 3.66±0.57$^{a}$ | 24.66±0.1$^{b}$ |
| **CP2-B** | 5.6±0.57$^{a}$ | 23.33±2.18$^{c}$ | 3.66±0.57$^{a}$ | 23.33±0.08$^{c}$ |
| **CP2-E** | 4.6±0.57$^{b}$ | 25.66±2.15$^{b}$ | 3.66±057$^{a}$ | 24.33±0.18$^{b}$ |
| **CP2-S** | 4.6±0.57$^{a}$ | 24.60±0.27$^{b}$ | 3.66±0.57$^{a}$ | 24.66±0.35$^{b}$ |
| **NPK-B** | 3.9±0.57$^{c}$ | 26.63±0.26$^{a}$ | 2.33±0.57$^{b}$ | 26.33±0.01$^{a}$ |
| **NPK-E** | 3.6±0.57$^{c}$ | 26.54±0.24$^{a}$ | 2.33±0.57$^{b}$ | 26.66±0.02$^{a}$ |
| **NPK-S** | 3.9±0.57$^{c}$ | 26.72±0.20$^{a}$ | 2.33±0.57$^{b}$ | 26.33±0.05$^{a}$ |

Means±SD followed by the same letter in a column are not significantly different at $P < 0.05$

### III.1.3.3 Assessment of the incidence and severity of attacks

After four weeks of transplanting, the sweet pepper plants were principaly attacked by the Wilt. both in pot and field experiments (Figure32 ).

**Figure 32:** Wilt observed in field and pot experiments

### III.1.3.3.1 Disease incidence

#### III.1.3.3.1.1 Production in pot experiment under net

The percentage of disease incidence presented in figure 33 shows that, sweet pepper plants cultivated from the treatments NPK-E(40.5 %), CP1-E(26.5 %) and CP2-E(26.9 %) were significantly attacked by the wilt than the other treatments such as NPK-B(10.6 %), NPK-S(19.5 %), CP1-B(3.3 %), CP1-S(7.2 %), CP2-B(4.3 %) and CP2-S(14.8 %) compared to the controls ( C-B (50.3 %) C-E (69.9 %) and C-S (62. 3 %). CP1-B and CP2-B had the lowest percentage of the disease incidence.

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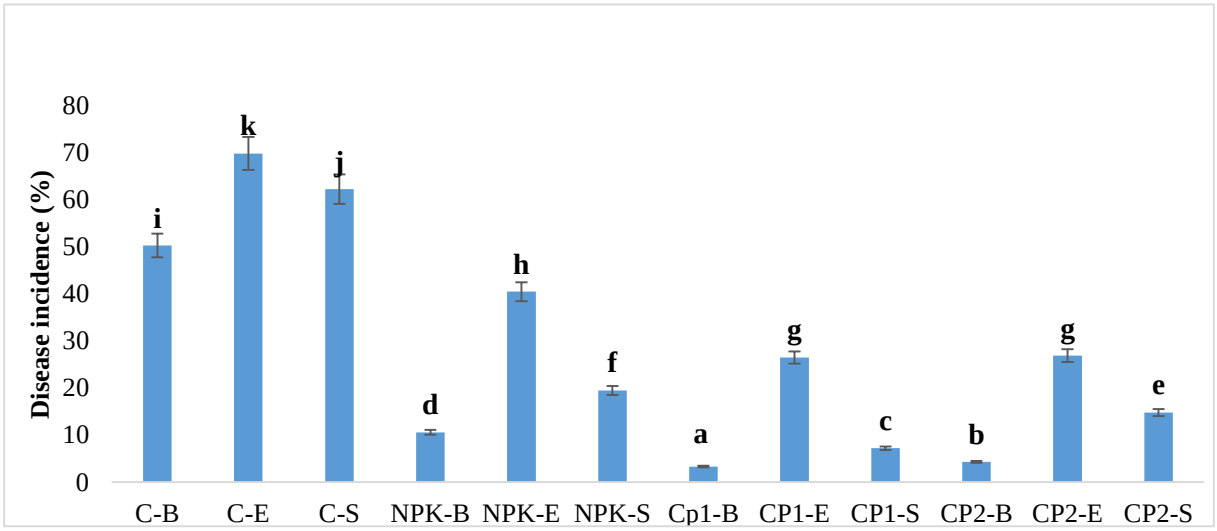


**Figure 33:** Effect of treatments on disease incidence after four weeks of transplanting under pot experiment/Bar charts with the same letter are not significantly different at P<0.05.

#### III.1.3.3.1.2 Production under field experiment

Compared to the controls (figure 34), CP1-B (15.5 %) and CP2-B (15.4 %) had the lowest disease incidence percentage, following by CP1-S (22.22%) and CP2-S (20.1%). On the contrary, plants grew from NPK-E (75.9 %) were significanly affeted by the disease while NPK-B (%33.6) and NPK-S (35.5%) had approximately the same percentage.

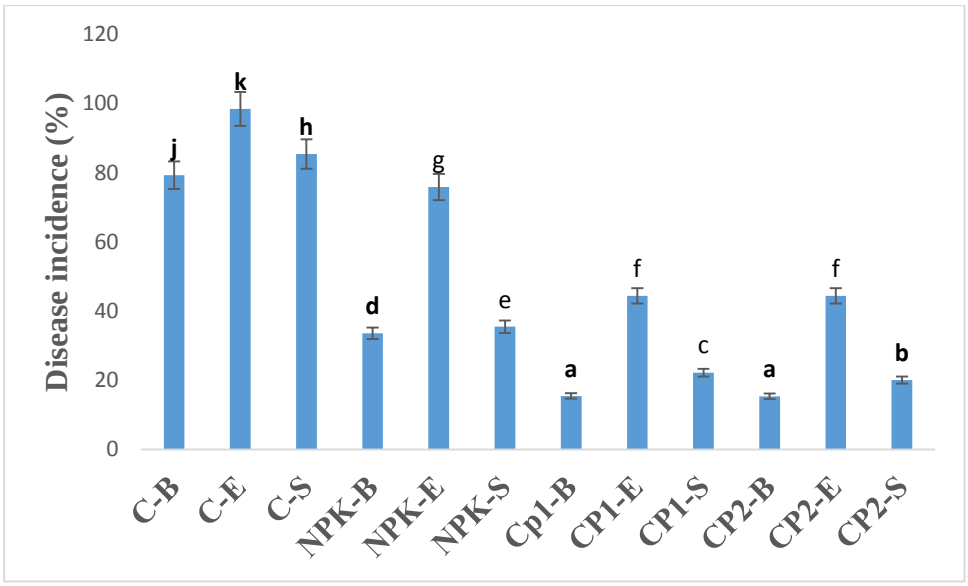


**Figure 34:** Effect of treatments on disease incidence after four weeks of transplanting under field experiment /Bar charts with the same letter are not significantly different at P<0.05.

### III.1.3.3.2 Disease severity

#### III.1.3.3.2.1 Production in pot experiment under net

After four weeks of transplanting (figure 35), the plants were not severely attacked from treatments CP1-B (7.5 %) and CP2-B (7.6 %) compared to the treatment NPK-S (20.1%) while the highest percentage of the disease severity was observed from the treatments NPK-E (47.5 %), CP1-E (40.6 %) and CP2-E(40.3 %). Figure 36 presents that the percentages of the disease severity of the treatments CP1-B, CP2-B, CP1-S, CP2-S, NPK-B and NPK-S remained the same after six weeks of transplanting except NPK-E (59.6 %) which significantly increased than the treatment CP1-E (47.2 %) and CP2-E (46.3 %) which in turn slightly increased.

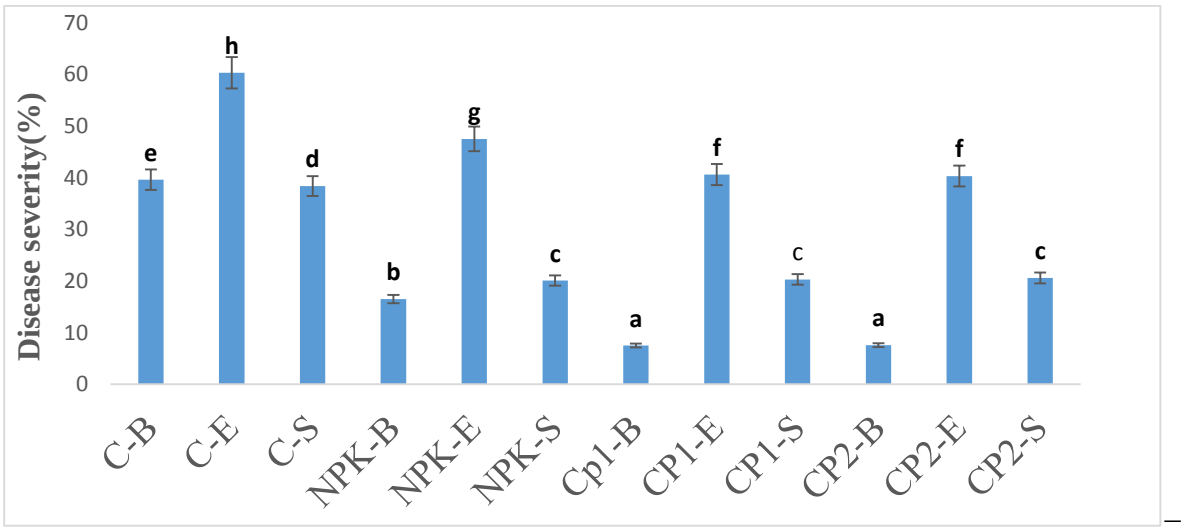

**Figure 35:**Effect of treatments on disease severity after four weeks of transplanting under pot experiment /Bar charts with the same letter are not significantly different at P<0.05.

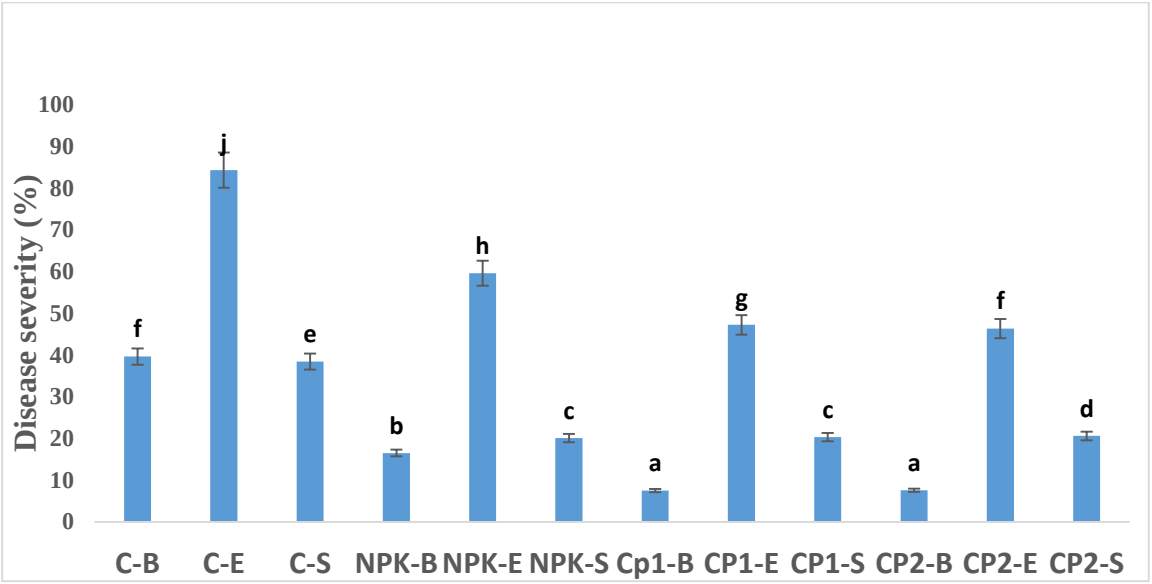


**Figure 36:**Effect of treatments on disease severity after six weeks of transplanting under pot experiment /Bar charts with the same letter are not significantly different at P<0.05.

### III.1.3.3.2.2 Production under field experiment

CP1-B (10.5%) and CP2-B (10.3%) presented the lowest percentage of disease severity. NPK-S (29.2%) and NPK-B (28.6%) had nearly the same percentage of the disease severity (figure 37). At the end of six weeks, as the results presented in the figure 38, the percentages of the disease severity of the treatments (CP1-B, CP2-B, CP1-S, CP2-S, NPK-B and NPK-S remained the same after six weeks of transplanting except NPK-E (69.8 %) which also significantly increased than the treatment CP1-E (45.2 %) and CP2-E (44.4 %) which in turn slightly increased ( figure 38).

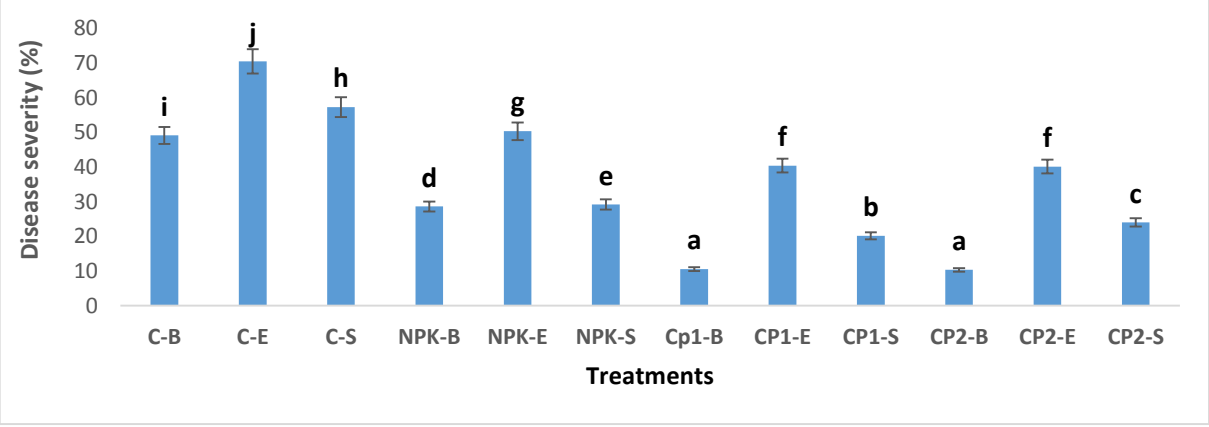


**Figure 37:** Effect of treatments on disease severity after four weeks of transplanting under field experiment /Bar charts with the same letter are not significantly different at P<0.

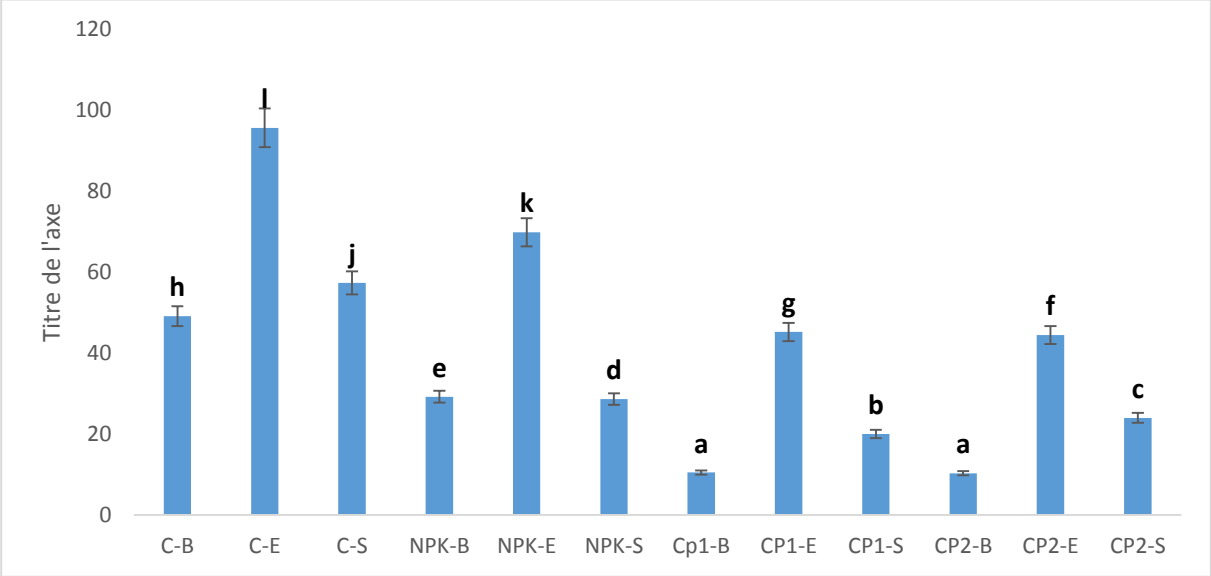


**Figure 38:**Effect of treatments on disease severity after six weeks of transplanting under field experiments /Bar charts with the same letter are not significantly different at P<0.05.

### III.1.3.4. Fruit yield in pot and field experiments

#### III.1.3.4.1 The number of fruit, fruit length, fruit diameter and fruit weight

The fruits harvested from the plants grew with treatments CP1-B, CP1-E, CP1-S, CP2-B, CP2-E and CP2-S had the number of fruits, fruit length, fruit diameter and fruit weight significantly higher than those harvested from the plants treated with NPK-B, NPK-E and NPK-S (table 21). In field experiment, the number of fruits had significantly increased with the increasing kg of the compost from the treatments CP1-B (16 fruits) and CP1-S (16fruits) to the treatments CP2-B (19 fruits), and CP2-S (18 fruits). Likewise, the fruit length significantly increased with the increasing amount of compost which accounted 7.6cm, 7.3cm, 7.4cm, 8.4 cm, 8.3cm and 8.5cm respectively for CP2-S, CP1-E, CP1-S, CP2-B, CP2-E and CP1-B. The case was not the same in pot experiment. Plant treated with the treatments CP1-B (pot experiment: number of fruit:11, fruit length:7.6cm, fruit diameter:6.3cm, fruit weight: 74.95g and field experiment: fruit diameter:6.9cm and fruit weight: 89.89g) and CP2-B (pot experiment: number of fruit: 11, fruit length: 7.6cm, fruit diameter: 6.3cm and fruit weight: 75.84g and field experiment: number of fruit: 19, fruit length: 8.4cm, fruit diameter: 6.9cm and fruit weight: 97.52g) had the number of fruits. length, fruit diameter and fruit weight significantly higher than the plants treated with the other treatments.

**Table 21**: Effect of treatments on the number of fruit, fruit length, fruit diameter and fruit weight

| | Field experiment | | | | Pot experiment | | | |
|---|---|---|---|---|---|---|---|---|
| **T** | **No. of fruit per plant** | **Fruit length (cm).** | **Fruit diameter (cm)** | **Fruit weight(g)** | **No. of fruit per plant** | **Fruit length (cm).** | **Fruit diameter (cm)** | **Fruit weight(g)** |
| **CP1-B** | 15.8±5.6$^{b}$ | 7.6±0.6$^{b}$ | 6.9±4.5$^{a}$ | 89.89±1.12$^{b}$ | 10.6±2.8$^{a}$ | 7.6±0.1$^{a}$ | 6.3±0.45$^{a}$ | 74.95±0.49$^{a}$ |
| **CP1-E** | 14.9±1.5$^{c}$ | 7.3±1.0$^{b}$ | 6.8±0.5$^{a}$ | 88.78±0.05$^{b}$ | 10.6±1.4$^{a}$ | 7.5±0.7$^{a}$ | 6.2±0.57$^{a}$ | 71.91±0.57$^{a}$ |
| **CP1-S** | 15.5±2.6$^{b}$ | 7.4±0.6$^{b}$ | 6.8±0.7$^{a}$ | 87.21±0.01$^{b}$ | 10.9±3.0$^{a}$ | 7.6±1.2$^{a}$ | 6.1±0.04$^{a}$ | 75.36±1.46$^{a}$ |
| **CP2-B** | 18.9±2.4$^{a}$ | 8.4±0.7$^{a}$ | 6.9±0.6$^{a}$ | 97.52.±0.05$^{a}$ | 11.3±4.5$^{a}$ | 7.6±1.5$^{a}$ | 6.3±0.6$^{a}$ | 75.84±1.34$^{a}$ |
| **CP2-E** | 14.4±2.8$^{c}$ | 8.3±0.3$^{a}$ | 6.9±0.1$^{a}$ | 94.50±0.7$^{a}$ | 10.6±0.8$^{a}$ | 7.5±0.8$^{a}$ | 6.1±0.7$^{a}$ | 74.63±0.15$^{a}$ |
| **CP2-S** | 18.2±1.4$^{a}$ | 8.5±0.4$^{a}$ | 6.8±0.8$^{a}$ | 95.92±0.06$^{a}$ | 11.3±0.1$^{a}$ | 7.5±0.3$^{a}$ | 6.2±0.5$^{a}$ | 73.75±1.57$^{a}$ |
| **NPK-B** | 10.3±2.5$^{d}$ | 6.4±0.9$^{c}$ | 5.5±0.10$^{b}$ | 72.80±0.02$^{c}$ | 5.6±0.3$^{b}$ | 6.5±0.10$^{b}$ | 5.2±0.6$^{b}$ | 59.53±0.6$^{b}$ |
| **NPK-E** | 9.9±0.5$^{d}$ | 6.3±0.4$^{c}$ | 5.4±0.2$^{b}$ | 70.96±0.04$^{c}$ | 5.3±0.8$^{b}$ | 6.5±012$^{b}$ | 5.3±0.9$^{b}$ | 58.89±0.37$^{b}$ |
| **NPK-S** | 10.3±0.9$^{d}$ | 6.5±0.5$^{c}$ | 5.5±0.9$^{b}$ | 75.61±0.1$^{c}$ | 5.1±0.4$^{b}$ | 6.6±1.1$^{b}$ | 5.1±0.4$^{b}$ | 61.48±0.57$^{b}$ |
| **C-B** | / | / | / | / | / | / | / | / |
| **C-E** | / | / | / | / | / | / | / | / |
| **C-S** | / | / | / | / | / | / | / | / |

Means±SD followed by the same letter in a column are not significantly different at $P < 0.05$

/= Plants did not produce fruits or fruits produced were not marketable

### III.1.3.4.2 Fruit yield (Kg $m^{-2}$) in pot and field experiments

Figures 39 shows that all the plants cultivated with CP1-B, CP1-E, CP1-S, CP2-B, CP2-E and CP2-S had the maximum fruits yield per $m^2$ higher than the plants grew with NPK-B, NPK-E and NPK-S both in pot and field experiments. The highest fruits yield per $m^2$ was: pot experiment, 10.6 kg/$m^2$ and 9.9 kg/$m^2$ and field experiment, 11.6 kg/$m^2$ and 9.93 kg/$m^2$, respectively, in CP2-B and CP1-B plots. The minimum fruits yield per $m^2$ were: pot experiment, 7.2 kg/$m^2$ and 7.3 kg/$m^2$ and field experiment,7.9 kg/$m^2$ and 7.55 kg/$m^2$ ,respectively, in CP1-S, CP2-S plots. Also, the lowest fruits yield was produced in NPK-E plots, pot experiment: 3.43 kg/$m^2$ and field: 3.43 kg/$m^2$.

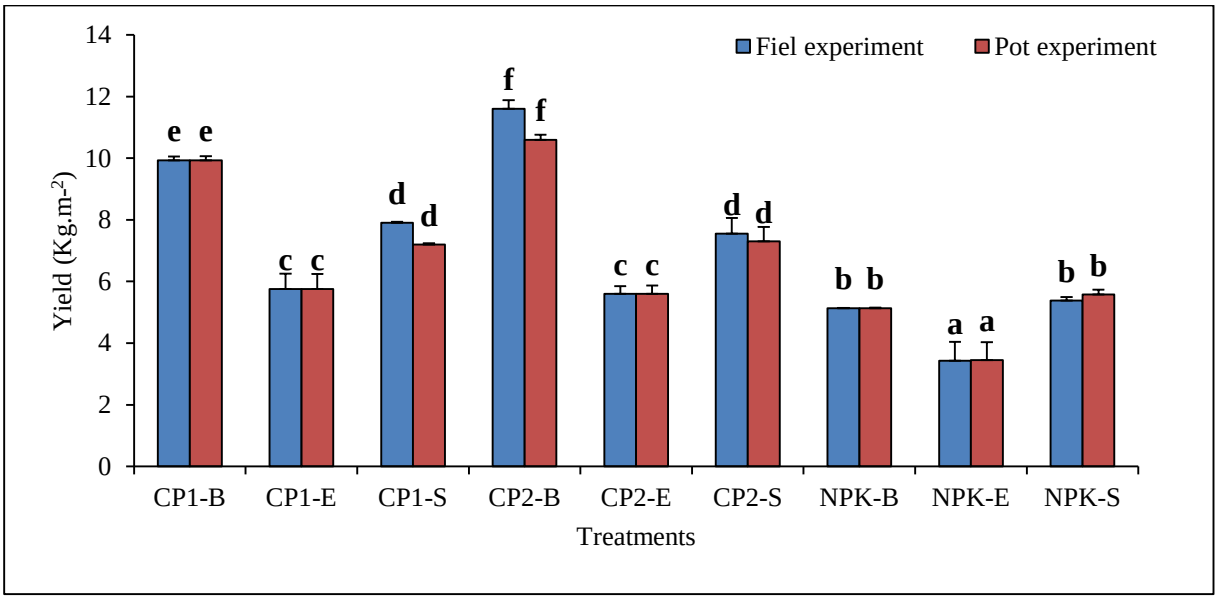


**Figure 39:** Effects of soil amendment and spray treatments on fruit yield of sweet pepper / Bar charts with the same letter are not significantly different at P<0.05 both in pot and field experiments.

### III.1.3.5 Organoleptic analysis

Overall, fruits harvested from treatments CP1-B, and CP2-B were more acceptable than those harvested from the other treatments (CP1-E, CP2-E, CP1-S, CP2-S NPK-B, NPK-E and NPK-S) both in pot and field experiments. In pot experiment, fruits harvested from CP1-B and CP2-B had the heghest score in terms of appearence/colour (CP1-B :8.66 and CP2-B : 8.33 ), size ( CP1-B : 7.56 and CP2-B : 7.66), taste ( CP1-B : 8.33 and CP2-B : 8.33 ) odor (CP1-B : 7.46 and CP2-B : 7.85) and sweetness (CP1-B :7.66 and CP2-B :7.66 ) compared to those obtained from CP1-E, CP1-S, CP2-E, CP2-S, NPK-B, NPK-E and NPK-S.

The same pattern was also observed under field experiment where fruits harvested from CP1-B and CP2-B had the highest score in terms of appearence/colour (CP1-B :8.33 and CP2-B :8.63 ), size ( CP1-B : 8.29 and CP2-B :8.33 ), taste ( CP1-B :8.36 and CP2-B :8.62 ) odor ( CP1-B :7.55 and CP2-B : 7.54) and sweetness (CP1-B :7.39 and CP2-B : 7.33) compared to those obtained from CP1-E, CP1-S, CP2-E, CP2-S, NPK-B, NPK-E and NPK-S ( figure 40,41 and table 22).

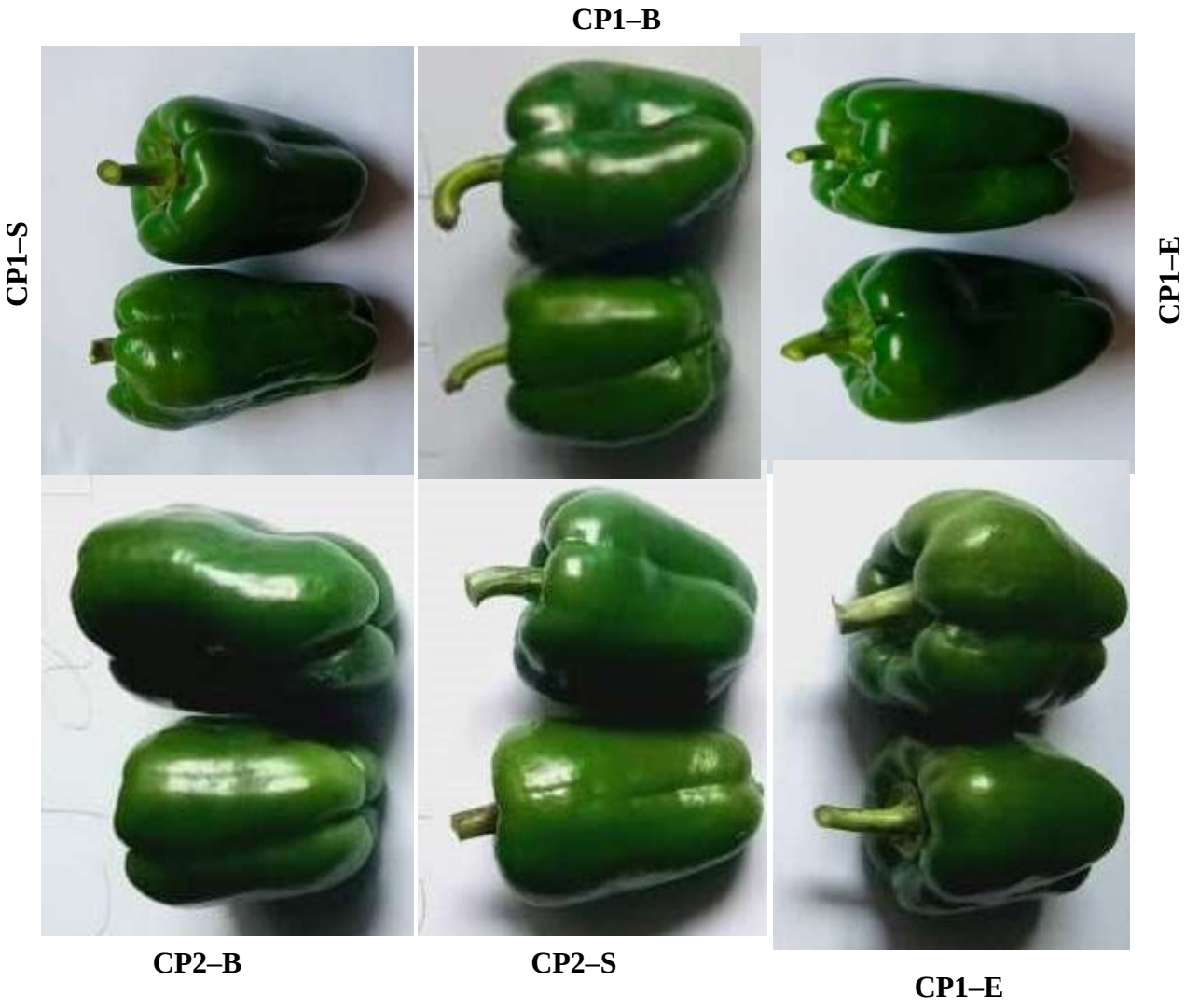


**Figure 40:** Sweet pepper fruits harvested from CP1–B, CP1–E, CP1–S, CP2–B, CP2–E and CP2–S plots

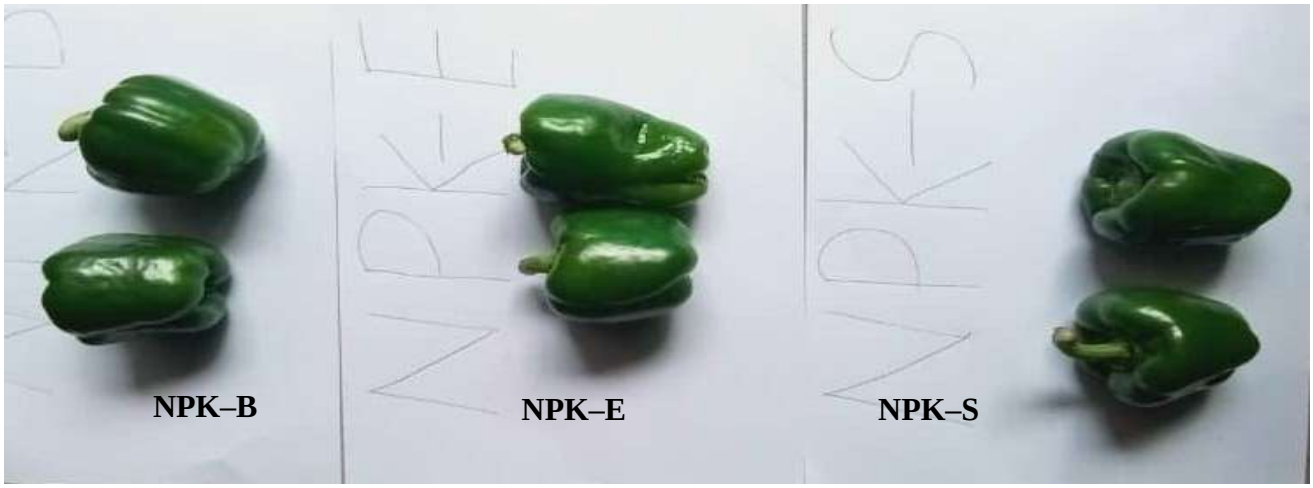


**Figure 41:Sweet pepper fruits harvested from NPK–S, NPK–E and NPK–B plots**

**Table 22**: Effect of treatments on the organoleptic characteristics of sweet peppers after 14 days of storage at 16°C

| **Field experiment : organoleptic analysis of fruit** | | | | | |
|---|---|---|---|---|---|
| | **appearenceColour** | **Size/ Shape** | **Taste** | **Odor/aroma** | **Sweetness** |
| **C1-B** | 8.33 ± 0.57$^{a}$ | 8.29 ± 0.57$^{a}$ | 8.36 ± 0.57$^{a}$ | 7.55 ±1.15$^{a}$ | 7.39 ± 1.73$^{a}$ |
| **C1-E** | 6.36 ± 0.57$^{c}$ | 6.56 ± 0.57$^{c}$ | 7.48 ± 0.57$^{b}$ | 5.65 ± 0.57$^{c}$ | 5.53 ± 0.57$^{c}$ |
| **C1-S** | 7.32 ± 0.57$^{b}$ | 7.34 ± 0.57$^{b}$ | 7.66 ± 0.57$^{b}$ | 6.33 ± 0.57$^{b}$ | 6.33 ± 0.57$^{b}$ |
| **C2-B** | 8.63 ± 0.57$^{a}$ | 8.33 ± 0.57$^{a}$ | 8.62 ± 0.57$^{a}$ | 7.54 ± 1.15$^{a}$ | 7.33 ± 1.73$^{a}$ |
| **C2-E** | 6.46 ± 0.57$^{c}$ | 6.45 ± 1.22$^{c}$ | 7.33 ± 0.57$^{b}$ | 5.66 ± 0.57$^{c}$ | 5.33 ± 0.57$^{c}$ |
| **C2-S** | 7.66 ± 0.33$^{b}$ | 7.33 ± 0.57$^{b}$ | 7.36 ± 0.57$^{b}$ | 6.33 ± 0.57$^{b}$ | 6 ± 0 .35$^{b}$ |
| **NPK-B** | 7.22 ± 0.57$^{b}$ | 7.66 ± 0.57$^{b}$ | 8.55 ± 0.57$^{a}$ | 6.33 ± 1.15$^{b}$ | 6.33 ± 0.57$^{b}$ |
| **NPK-E** | 5.33 ± 0.57$^{c}$ | 5.51 ± 0.44$^{d}$ | 6.66 ± 0.57$^{c}$ | 5.66 ± 0.57$^{b}$ | 5.33 ± 0.57$^{c}$ |
| **NPK-S** | 7.22 ± 0.57$^{b}$ | 7.56 ± 0.57$^{b}$ | 8. 22± 0.26$^{a}$ | 6.56 ± 0.57$^{a}$ | 6.39 ± 0.57$^{b}$ |
| **Pot experiment: organoleptic analysis of fruit** | | | | | |
| | **Appearence/Colour** | **Size/ Shape** | **Taste** | **Odor/Aroma** | **Sweetness** |
| **C1-B** | 8.66 ± 0.12$^{a}$ | 7.56 ± 0.57$^{a}$ | 8.33 ± 1.73$^{a}$ | 7.46 ± 1.15$^{a}$ | 7.66 ± 1.73$^{a}$ |
| **C1-E** | 6.33 ±1.15$^{c}$ | 6.43 ±1.15$^{b}$ | 6.26 ± 0.57$^{c}$ | 5.56 ± 0.57 $^{c}$ | 5.33 ± 0.57$^{c}$ |
| **C1-S** | 7.26 ± 0.5c | 7.66 ± 1.15$^{b}$ | 7.55 ± 1.73$^{b}$ | 6.24 ± 0.57$^{a}$ | 6.33 ± 0.57$^{b}$ |
| **C2-B** | 8.33 ± 0.57$^{a}$ | 7.66 ± 0.57$^{a}$ | 8.33 ± 0.57$^{a}$ | 7.85 ± 1.15$^{a}$ | 7.66 ± 1.73$^{a}$ |
| **C2-E** | 6.33 ± 1.15$^{c}$ | 6.66 ± 0.57$^{b}$ | 6 .22± 1.15$^{b}$ | 5.66 ± 0.57$^{c}$ | 5.33 ± 0.57$^{c}$ |
| **C2-S** | 7.66 ± 0.57$^{c}$ | 7.36 ± 1.15$^{b}$ | 7. 44± 1.73$^{b}$ | 6.44 ± 0.57$^{a}$ | 6.55 ± 0.57$^{b}$ |
| **NPK-B** | 7.33 ± 0.57$^{b}$ | 7.43 ± 0.57$^{a}$ | 7.43 ±1.15$^{b}$ | 7.53 ± 1.15$^{a}$ | 6.23 ±0.57$^{b}$ |
| **NPK-E** | 5 ± 0.24$^{d}$ | 5 ± 0.15$^{c}$ | 6.33 ± 1.15$^{c}$ | 5.33 ± 0.57$^{b}$ | 5.33 ± 0.57$^{c}$ |
| **NPK-S** | 7.23 ± 0.57$^{b}$ | 7.33 ± 0.57$^{a}$ | 7.54 ± 0.57 $^{b}$ | 6.63 ± 0.57$^{a}$ | 6.34 ± 0.57$^{b}$ |

Means±SD followed by the same letter in a column are not significantly different at $P < 0.05$

### III.1.3.6 Fruit analysis

#### III.1.3.6.1 Effect of treatments on postharvest conservation of sweet pepper fruits.

Sweet pepper fruits harvested from the plants grew with treatments CP1-B and CP2-B had a long shelf life, which accounted respectively 90 days when stored at 4 $^0$C and 26 days when stored in an ambient temperature, which was significantly higher than those harvested from the plants cultivated with NPK-B; NPK-E and NPK-S (17 days at 4$^0$C and 11 days ambiant temperature) both in pot and field experiments (figure 42 and 43). The minimum shelf life was accounted by fruits harvested from the treatments CP1-E; CP1-S; CP2-E and CP2-S which exhibited 87 days stored at 4 $^0$ C and 21 days stored in an ambient temperature. In addition, after 26 days of storage (ambient temperature) the fruits obtained from CP1-B and CP2-B were becoming dry instead of rotting while those from the other treatment were rotting (figure 44).


**NPK–B (17 days)** **CP2–B (90 days)** **CP1–B (90 days)**

**Figure 42:** Sweet pepper fruits harvested from plots CP1–B, CP2–B and NPK–B and stored at 4°C


**Figure 43:** Sweet pepper fruits harvested from plots CP1–B, CP2–B and NPK–B and stored in an ambiant temperature

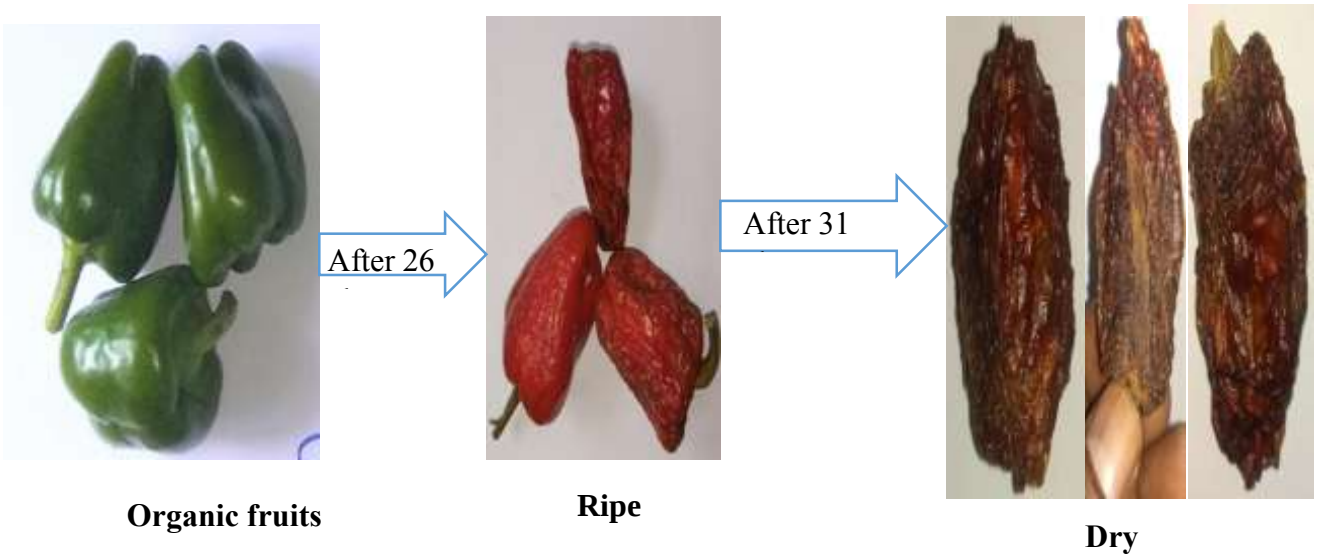


**Figure 44:** The physical transformation of organic sweet pepper fruits (CP1–B, CP2–B) stored in an ambient temperature after 30 days.

### III.1.3.6.2 Fruits'pH

Data from the figure 45 illustrates that in pot experiment all the fruits harvested from the plants cultivated with CP1-B (4.32), CP1-E (4.27), CP1-S (4.43), CP2-B (4.32), CP2-E (4.54) and CP2-S (4.37) had the pH, which was significantly ($P<0.05$) lower than those harvested from the treatments NPK-B (5.16), NPK-E (5.26) and NPK-S (5.39). The same pattern was also observed in the field experiment.

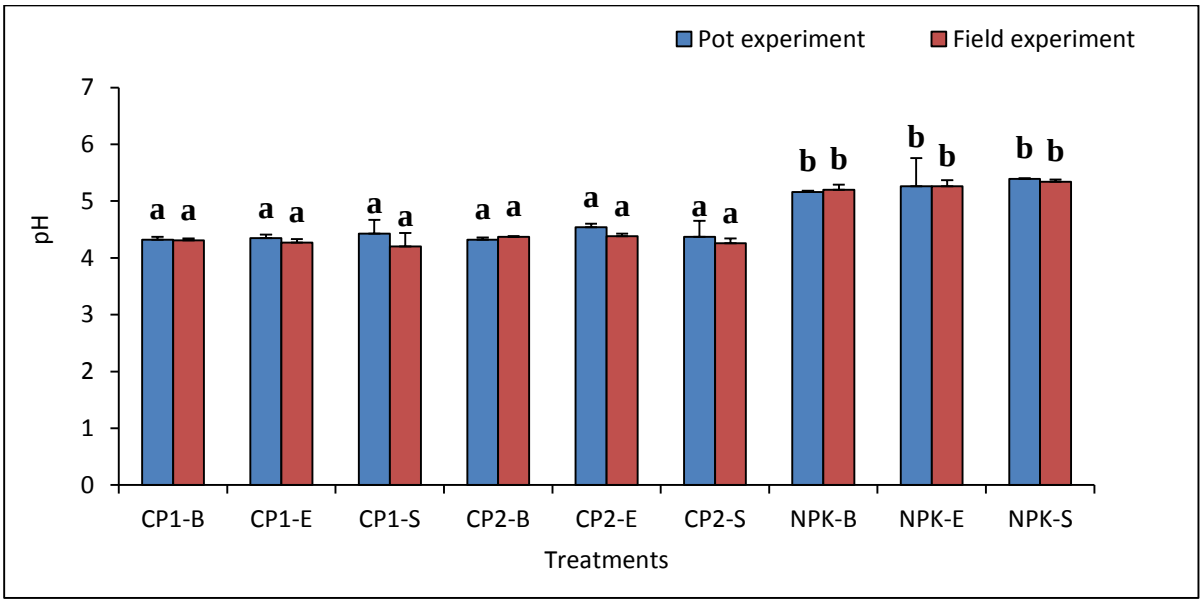


**Figure 45:** Effects of soil amendment and spray treatments on the pH of sweet peppers fruits. Bar charts with the same letter are not significantly different at $P<0.05$ both in pot and field experiments.

### III.1.3.6.3 Effet of treatments on sweet pepper nutritional properties

#### III.1.3.6.3.1 Macronutrients content

The percentage of the water content of fruits produced from CP1-B, CP1-E, CP1-S, CP2-B, CP2-E and CP2-S, which ranged from 89.03 to 89.33% in pots and 89.23 to 89.28% in field experiment was significantly lower than those harvested from the treatments NPK-B, NPK-E and NPK-S, which respectively ranged from 94.23 to 96.97% in pot experiment and 94.88 to 95.53% under field experiment. Cassava peels compost soil amendment significantly decreased the water content of the fruits compared to the conventional treatment which produced fruits with the highest water content. The former had the percentage of the total lipid ranged in pot experiment from 14.22 to 15.22% and in field experiment 14.15 to 15.32%, significantly higher than the percentage of the fruits harvested from treatments NPK-B, NPK-E and NPK-S, with the highest concentration in fruits from CP1-B and CP2-B plots.

The highest concentration of proteins was found in fruits from CP1-B (pot experiment: 0.85 g/100g and field: 0.88 g/100g) and CP2-B (pot experiment: 0.97 g/100g and field: 0.98 g/100g). The concentration of the total ash, total sugar as well as the percentage of the crude fibre from treatments CP1-B, CP1-E, CP1-S, CP2-B, CP2-E and CP2-S were significantly higher than those observed from the treatments NPK-B, NPK-E and NPK-S both in pot and field experiments (table 23).

**Table 23:** Effects of soil amendment and spray treatments on proximate composition of sweet pepper fruits

| Pot experiment | | | | | | |
|---|---|---|---|---|---|---|
| T | Total sugar (mg/100g) | Total lipids (%) | Crude fiber ( %) | water content ( %) | Protein (g/100g) | total ash (g/100g) |
| **CP1-B** | 5.60±0.01$^{a}$ | 14.49±0.02$^{b}$ | 14.15±0.02$^{a}$ | 89.22±0.19$^{b}$ | 0.85±0.01$^{b}$ | 0.91±0.06$^{a}$ |
| **CP1-E** | 5.51±0.01$^{a}$ | 14.22±0.07$^{b}$ | 14.03±0.01$^{a}$ | 89.31±0.13$^{b}$ | 0.80±0.01$^{b}$ | 0.90±0.05$^{a}$ |
| **CP1-S** | 5.61±0.01$^{a}$ | 14.29±0.04$^{b}$ | 14.34±0.04$^{a}$ | 89.03±0.06$^{b}$ | 0.84±0.01$^{b}$ | 0.92±0.01$^{a}$ |
| **CP2-B** | 5.69±0.01$^{a}$ | 15.11±0.08$^{a}$ | 14.31±0.06$^{a}$ | 89.24±0.10$^{b}$ | 0.96±0.01$^{a}$ | 0.93±0.02$^{a}$ |
| **CP2-E** | 5.31±0.01a | 15.02±0.05$^{a}$ | 14.42±0.05$^{a}$ | 89.25±0.05$^{b}$ | 0.91±0.05$^{a}$ | 0.94±0.13$^{a}$ |
| **CP2-S** | 5.72±0.02$^{a}$ | 15.01±0.01$^{a}$ | 14.52±0.01$^{a}$ | 89.33±0.01$^{b}$ | 0.92±0.003$^{a}$ | 0.95±0.23$^{a}$ |
| **NPK-B** | 4.45±0.01$^{b}$ | 13.89±0.05$^{c}$ | 13.87±0.05$^{b}$ | 95.48±0.06$^{a}$ | 0.75±0.01$^{c}$ | 0.79±0.04$^{b}$ |
| **NPK-E** | 4.58±0.04$^{b}$ | 13.78±0.08$^{c}$ | 13.76±0.49$^{b}$ | 94.23±0.02$^{a}$ | 0.70±0.01$^{c}$ | 0.78±0.01$^{b}$ |
| **NPK-S** | 4.61±0.04$^{b}$ | 13.95±0.06$^{c}$ | 13.69±0.60$^{b}$ | 96.97±0.02$^{a}$ | 0.74±0.03$^{c}$ | 0.78±0.21$^{b}$ |
| **Field experiment** | | | | | | |
| T | Total sugar (mg/100g) | Total lipids (%) | Crude fiber ( %) | water content ( %) | Protein (g/100g) | total ash (g/100g) |
| **CP1-B** | 5.71±0.01$^{a}$ | 14.33±0.15$^{b}$ | 14.51±0.16$^{a}$ | 89.25±0.01$^{b}$ | 0.88±0.01$^{b}$ | 0.96±0.01$^{a}$ |
| **CP1-E** | 5.61±0.01$^{a}$ | 14.15±0.13$^{b}$ | 14.27±0.06$^{a}$ | 89.26±0.02$^{b}$ | 0.81±0.01$^{b}$ | 0.95±0.01$^{a}$ |
| **CP1-S** | 5.68±0.005$^{a}$ | 14.21 ±0.01$^{b}$ | 14.46±0.11$^{a}$ | 89.28±0.06$^{b}$ | 0.83±0.01$^{b}$ | 0.94±0.01$^{a}$ |
| **CP2-B** | 5.71±0.01$^{a}$ | 15.32±0.01$^{a}$ | 14.64±0.04$^{a}$ | 89.23±0.20$^{b}$ | 0.98±0.005$^{a}$ | 0.95±0.01$^{a}$ |
| **CP2-E** | 5.70±0.005$^{a}$ | 15.11±0.02$^{a}$ | 14.12±0.01$^{a}$ | 89.35±0.38$^{b}$ | 0.92±0.01$^{a}$ | 0.93±0.01$^{a}$ |
| **CP2-S** | 5.70±0.005$^{a}$ | 15.23±0.15$^{a}$ | 14.30±0.01$^{a}$ | 89.27±0.04$^{b}$ | 0.94±0.01$^{a}$ | 0.96±0.01$^{a}$ |
| **NPK-B** | 4.81±0.78$^{b}$ | 13.58±0.01$^{c}$ | 13.11±0.01$^{b}$ | 94.80±0.32$^{a}$ | 0.76±0.005$^{c}$ | 0.78±0.09$^{b}$ |
| **NPK-E** | 4.38±0.01$^{b}$ | 13.38±0.20$^{c}$ | 13.31±0.01$^{b}$ | 95.53±0.14$^{a}$ | 0.74±0.01$^{c}$ | 0.72±0.15$^{b}$ |
| **NPK-S** | 4.63±0.04$^{b}$ | 13.58±0.005$^{c}$ | 13.41±0.01$^{b}$ | 94.88±0.02$^{a}$ | 0.77±0.005$^{c}$ | 0.75±0.01$^{b}$ |

Means±SD followed by the same letter in a column are not significantly different at $P < 0.05$

### III.1.3.6.3.2 Micronutrients content

#### III.1.3.6.3.2.1 Vitamin C

The highest concentrations in vitamin C (figure 46) were recorded in fruits harvested from CP1-B plot (pot experiment: 110.18 mg/100g and field: 114.94 mg/100g) and CP2-B plot (pot experiment: 111.21 mg/100g and field: 115.83 mg/100g), compared with those obtained from the other treatments. They were followed by fruits obtained from plants treated with CP1-E (pot experiment :100.60 mg/100g and field:100.23 mg/100g) , CP1-S (pot experiment: 100.44mg/100g and field: 1103.66 mg/100g), CP2-E (pot experiment :101.86 mg/100g and field: 100.23mg/100g) and CP2-S (pot experiment: 104.99mg/100g and field experiment: 10.3.66 mg/100g).

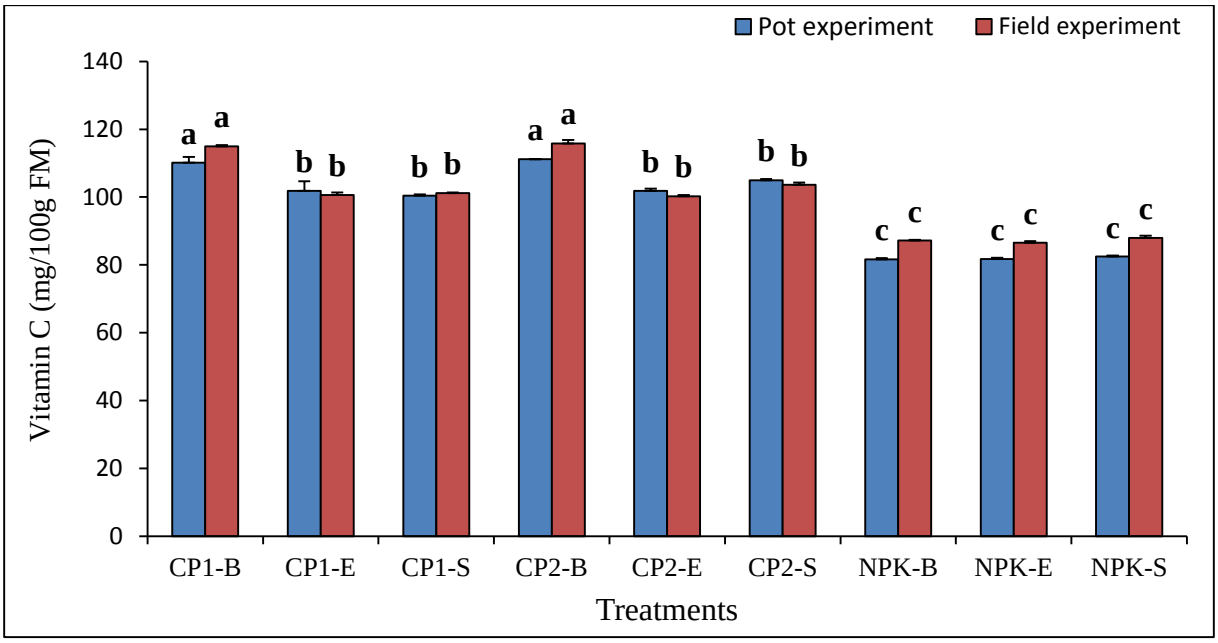


**Figure 46:** Effects of soil amendment and spray treatments on the concentration of vitamin C. Bar charts with the same letter are not significantly different at P<0.05 both in pot and field experiments.

### III.1.3.6.3.2.2 Minerals content

The concentrations of Ca, Mg, K, Na, Zn and Mn were significantly higher in sweet pepper fruits harvested from the treatments CP1-B, CP1-E, CP1-S, CP2-B, CP2-E and CP2-S than those obtained from fruits harvested from NPK-B, NPK-E and NPK-S both in pot and field experiments. The concentrations in fruits from the former treatments in P and Cu were significantly lower (table 24). However, The Na/k ratios of the fruits obtained from CP1-B, CP1-E, CP1-S, CP2-B, CP2-E and CP2-S were significantly lower than the fruit harvested from the treatments NPK-B, NPK-E and NPK-S, while their Na/k ratios ranged, respectively, from 0.72 to 0.83 in pot experiment and 0.69 to 0.72 in field experiment. On the contrary, they had the highest Ca/P ratios which varied, respectively, from 2.46 to 2.49 in pot experiment and 2.31 to 2.45 under field experiment (table 24).

**Table 24:** Effect of treatments on minerals content of sweet pepper fruit

| | Pot experiment: (mg/100g of DM) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **T** | **Ca** | **P** | **Mg** | **K** | **Na** | **Cu** | **Zn** | **Mn** | **Na/K** | **Ca/P** |
| **CP1-B** | 87,5±0,02 | 35.12±0.02 | 15.77±0.001 | 277.38±16.44 | 201,84±2,04 | 47.7±0.90 | 388.01±0.04 | 230.94±0.37 | 0.72±0.02 | 2.49±30.2 |
| **CP1-E** | 86,5±0,02 | 35.08±0.07 | 15.76±0.001 | 268.27±0.06 | 203.61±5.84 | 48.2±0.50 | 387.09±0.23 | 228,76 ± 0,38 | 0.75±0.04 | 2.46±45.1 |
| **CP1-S** | 87,4±0,31 | 35.23±0.002 | 15.69±0.001 | 259.10±0.70 | 200.98±0.57 | 48.7±0.1 | 389.33±2.08 | 229.68±0.18 | 0.77±0.05 | 2.48±50.7 |
| **CP2-B** | 87,9±0,04 | 35.26±0.001 | 15.54±0.02 | 271.96±12.58 | 207.96±1.49 | 49.5±0.60 | 398.02±0.89 | 230.48±0.09 | 0.76±0.03 | 2.49±65.4 |
| **CP2-E** | 87,4±0,03 | 35.30±0.002 | 15.71±0.002 | 244.89±12.85 | 203.60±3.50 | 49.5±0.55 | 387.12±0.32 | 231.54±0.04 | 0.83±0.07 | 2.47±0.58 |
| **CP2-S** | 87,5±0,05 | 35.31±0.05 | 15.72±0.001 | 258.96±1.30 | 206.51±1.58 | 49.1±0.52 | 384.10±0.43 | 232.5±0.01 | 0.79±0.04 | 2.47±45.9 |
| **NPK-B** | 78.4±5,32 | 40.65±0.60 | 11.84±0.002 | 116.04±0.71 | 192.52±6.49 | 57.7±0.20 | 185.15±0.54 | 199.97±0.16 | 1.65±0.15 | 1.92±0.18 |
| **NPK-E** | 78,9±5,43 | 39.9±0.005 | 11.78±0.002 | 115.56±0.25 | 198.50±1.16 | 57.7±0.32 | 190.11±3.60 | 198.56±0.02 | 1.71±0.63 | 1.97±0.48 |
| **NPK-S** | 79,6±0,19 | 40.1±0.18 | 11.85±0.007 | 116.53±1.02 | 195.27±5.24 | 57.4±2.25 | 190.02±2.24 | 199.19±0.12 | 1.67±0.9 | 1.98±0.56 |
| | **Field experiment: (mg/100g of DM)** | | | | | | | | | |
| | **Ca** | **P** | **Mg** | **K** | **Na** | **Cu** | **Zn** | **Mn** | **Na/k** | **Ca/p** |
| **CP1-B** | 82.53±0.02 | 34.6±0.43 | 14.2±0.1 | 272.9±2.34 | 195.9±5.77 | 43.2±0.76 | 231.1±0.01 | 215.3±0.24 | 0.71±0.01 | 2.38±45.8 |
| **CP1-E** | 80.20±4.03 | 34.6±0.10 | 14.0±0.04 | 270.7±0.39 | 195±5.54 | 42.5±0.52 | 248.1±34.74 | 211.5±1.57 | 0.72±0.02 | 2.31±40.9 |
| **CP1-S** | 80.36±0.31 | 34.1±0.10 | 14.4±0.1 | 260.1±11.8 | 188.3±1.02 | 43.2±0.04 | 228.2±0.10 | 215.1±0.15 | 0.72±0.05 | 2.35±36.7 |
| **CP2-B** | 84.62±0.62 | 34.6±0.41 | 14.7±0.01 | 282.8±4.66 | 199.3±0.15 | 45.36±0.22 | 230.6±0.50 | 217.7±2.54 | 0.70±0.06 | 2.44±35.7 |
| **CP2-E** | 84.48±0.03 | 34.4±0.40 | 14.6±0.15 | 272±0.99 | 188±0.79 | 43.8±1.18 | 230.4±0.66 | 219.6±1.39 | 0.69±0.6 | 2.45±40.9 |
| **CP2-S** | 84.54±0.05 | 34.5±0.15 | 14.5±0.15 | 271.9±1.50 | 189.5±0.07 | 46.6±2.85 | 230.2±0.27 | 216.5±0.55 | 0.69±0.8 | 2.43±0.57 |
| **NPK-B** | 79.13±0.65 | 42.6±0.55 | 12.1±1.26 | 100.2±1.07 | 159.2±1.17 | 47.8±4.99 | 198.2±0.27 | 191.05±3.87 | 1.58±0.7 | 1.85±0.02 |
| **NPK-E** | 79.40±0.52 | 41.9±0.17 | 12.6±0.05 | 132.1±5.11 | 161.7±0.37 | 51.2±0.84 | 197.5±0.31 | 191.3±7.39 | 1.22±0.25 | 1.89±0.014 |
| **NPK-S** | 79.31±0.45 | 43.1.3±0.09 | 11.5±0.41 | 123.9±4.47 | 157.9±0.34 | 50.1±0.11 | 193.1±11.20 | 191.9±6.26 | 1.27±0.30 | 1.83±0.013 |

Means±SD followed by the same letter in a column are not significantly different at $P < 0.05$

### III.1.3.6.3.3 Total polyphenols and flavonoids content of sweet pepper fruits

The highest total polyphenols content was recorded in sweet pepper fruits harvested from CP2-B plot (pot experiment: 33.35mg/100g and field: 37.83mg/100g), CP2-E (pot experiment: 30.57mg/100g and field experiment: 34.84 mg/100g) and CP2-S plot (pot experiment: 32.72mg/100g and field experiment: 35.54mg/100g). The lowest total polyphenol content was obtained from fruit harvested from the treatments NPK-B (pot experiment: 29.84mg/100g and field experiment: 29.99 mg/100g), NPK-E (pot experiment: 27.05 mg/100g and field experiment: 28.89mg/100g) and NPK-S (pot experiment: 28.98mg/100g and field experiment: 30.17mg/100g).

The highest concentration in total flavonoids was recorded from CP1-B (pot experiment: 110.3 mg/100g and field experiment: 125.4 mg/100g) and CP2-B (pot experiment: 113.1mg/100g and field experiment : 133.4 mg/100g) and the lowest concentration was observed in fruits harvested from NPK-B (pot experiment: 95.3 mg/100g and field experiment: 98.5mg/100g), NPK-E (pot experiment: 90.7 mg/100g and field experiment: 95.6 mg/100g) and NPK-S pot experiment :95.9 mg/100g and field experiment:98.8 mg/100g),(figure 47)

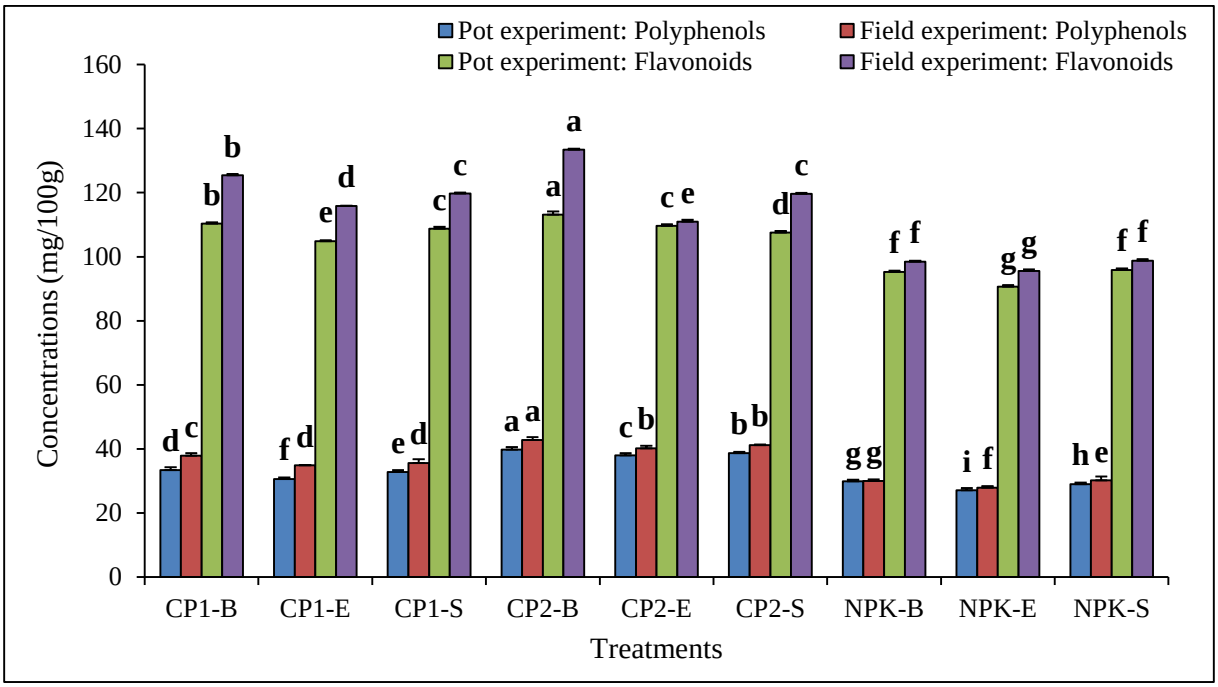


**Figure 47:** Effects of soil amendment and spray treatments on the total polyphenol and flavonoid content of sweet pepper fruits. Bar charts with the same letter are not significantly different at P<0.05 both in pot and field experiments.

### III.1.3.6.3.4 Antioxidant potential of sweet pepper fruits

#### III.1.3.6.3.4.1 Radical scavenging activity

The results of DPPH inhibition of the extracts of fruits harvested from different treatments are summarized in figure 48, which shows that extracts of fruits harvested from the treatments CP1-B (pot experiment: 80.9% and field experiment: 84.9%) and CP2-B (pot experiment:81.3% and field experiment: (85.1%) were the most effective DPPH radical scavengers**.** The extracts of fruits harvested from treatments NPK-B were also good radical scavengers with the inhibition of 71.2% and 72.9 %, respectively, in pot and field experiments. The fruits harvested from NPK-E (pot experiment: 55.1% and field experiment: 58.5 %) were considerably less effective radical scavengers compared to CP1-E (pot experiment: 61.9% and field experiment: 62.01%) and CP2-E (pot experiment: 61.1% and field experiment: 62.9%).

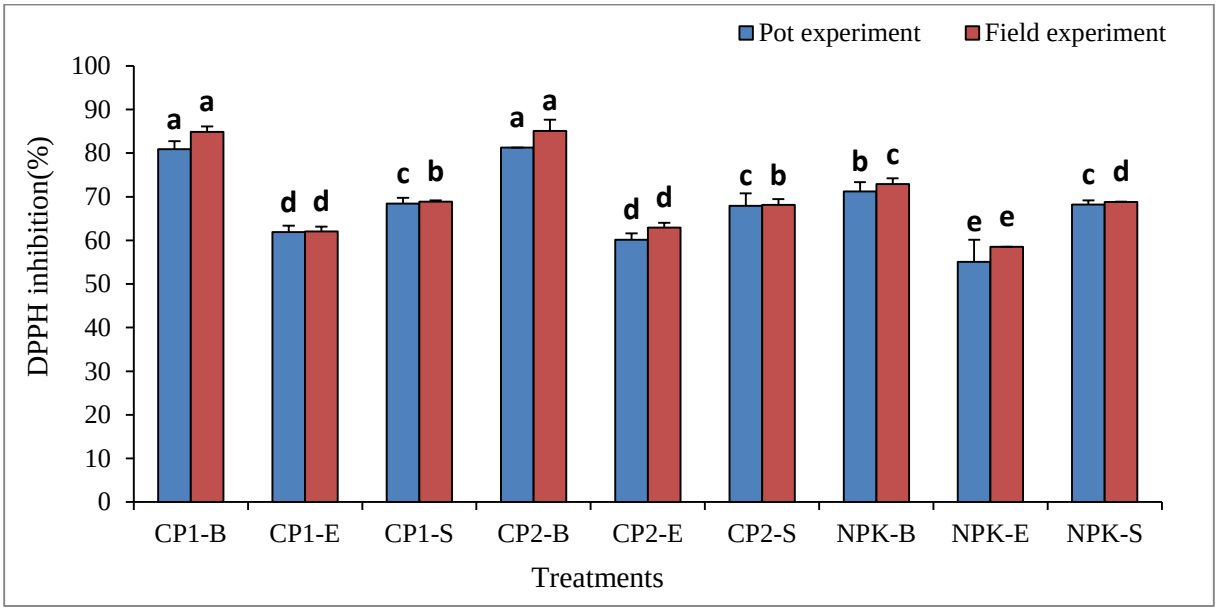


**Figure 48**: DPPH absorption inhibition (%) of sweet pepper fruit extracts. Bar charts with the same letter are not significantly different at $P<0.05$ both in pot and field experiments.

#### III.1.3.6.3.4.2 Total Antioxidant Capacity (TAC)

In general, all the fruits harvested from the treatments CP1-B, CP1-E, CP1-S, CP2-B, CP2-E and CP2-S had the total antioxidant capacity significantly higher than the fruits collected from the treatments NPK-B, NPK-E and NPK-S. The highest value of TAC was obtained from the fruits harvested from CP1-B (pot experiment: 112.84g/100g and field experiment: 113.30g/100g) and CP2-B (pot experiment:118.86g/100g and field experiment:

120.50113.30g/100g) compared to those harvested from NPK-B (pot experiment: 98.99g/100g and field experiment: 99.89g/100g), NPK-E (pot experiment:94.66 g/100g and field experiment: 98.95 g/100g) and NPK-S (pot experiment: 99.46 g/100g and field experiment: 99.97g/100g). Also, the TAC increased with the increasing amount of the compost mass (figure 49).

### III.1.3.6.3.4.3 Reducing Ferric Capacity (FRAP: Ferric Reducing Antioxidant Power)

It is illustrated in table 15 that, FRAP was significantly higher from fruit harvested from the plants of plots CP1-B (pot experiment: 25.32g/100g and field experiment: 27.95g/100g) and CP2-B (pot experiment: 26.90g/100g and field experiment: 29.89g/100g). The sweet pepper fruits of the treatments NPK-B (pot experiment: 18.89 g/100g and field experiment: 19.20g/100g), NPK-E (pot experiment: 14.41g/100g and field experiment: 15.97g/100g) and NPK-S (pot experiment: 20.98g/100g and field: 21.89 g/100g) had the FRAP value significantly lower. (Figure 49).

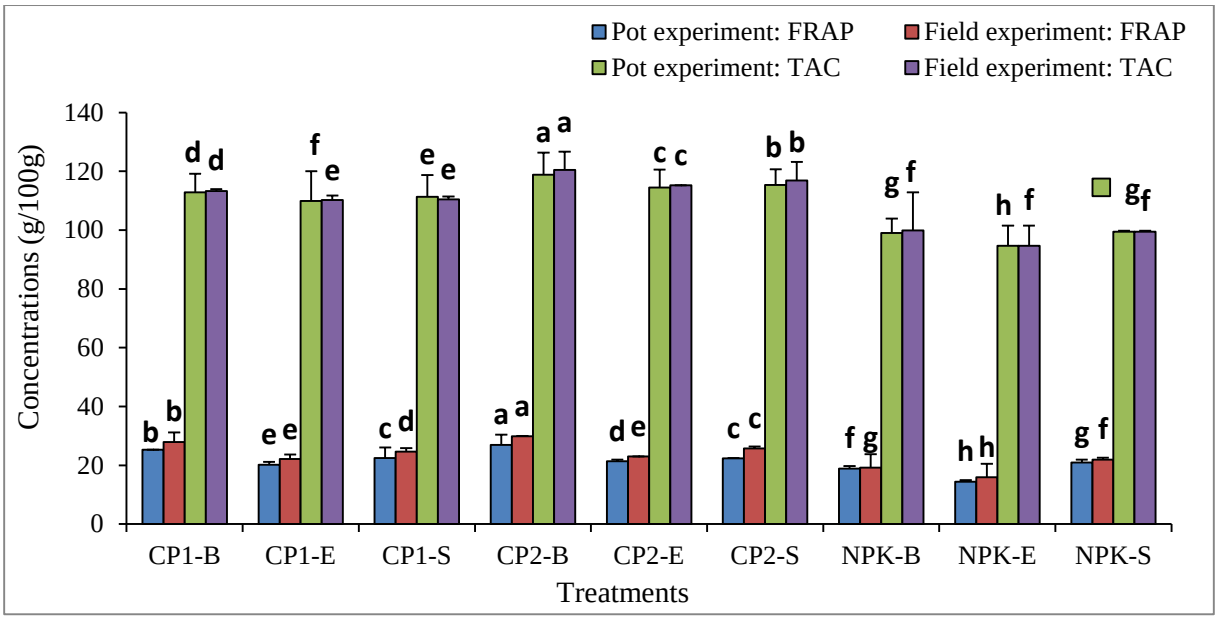


**Figure 49:** Ferric Reducing Antioxidant Power (FRAP) (g/100g) and Total Antioxidant Capacity (TAC) (g/100g) of sweet pepper fruit extracts. Bar charts with the same letter are not significantly different at P<0.05 both in pot and field experiments.

### III.1.3.6.3.5 Pesticide residues of sweet pepper fruit extracts

Results from the table 25 revealed that extracts of the fruits harvested from the plants of plots NPK-S, CP1-S and CP2-S contained pesticide residues while those harvested from the plants of plots NPK-B, NPK-E, CP1-B, CP1-E, CP1-B, CP2-B and CP2-E did not contain any pesticide residues. The concentrations of lambda-cyhalothrin detected in those fruits ranged, respectively, from: pot experiment (0.098 mg/kg and 0.095 mg/kg) and field experiment (0.189 mg/kg and 0.194 mg/kg). The fruits harvested from the field experiment had the highest concentration of lambda-cyhalothrin, which was above the authorized maximum residue limits (MRLs) of 0.05 mg/kg. The concentrations of lambda-cyhalothrin (0.199 mg/kg) detected from the extracts of farmers' fruits was similar to that obtained from the current field trial.

**Table 25:** Residues of lambda - cyhalothrin detected in sweet pepper fruits

| | **Residues (mg/kg)** | |
|---|---|---|
| **Treaments** | **Pot experiment** | **Field experiment** |
| **CP1-B** | 0 | 0 |
| **CP1-E** | 0 | 0 |
| **CP1-S** | 0.095±0.007[a] | 0.190±0.003[a] |
| **CP2-B** | 0 | 0 |
| **CP2-E** | 0 | 0 |
| **CP2-S** | 0.093±0.004[a] | 0.189±0.003[a] |
| **NPK-B** | 0 | 0 |
| **NPK-E** | 0 | 0 |
| **NPK-S** | 0.098±0.001[a] | 0.194±0.004[a] |
| | **Residues (mg/kg)** | |
| **Farmers' fruits** | | 0.199±0.004[a] |

Means±SD followed by the same letter in a column are not significantly different at $P < 0.05$

### III.1.3.6.3.6 Effects of cassava peels compost on soil qualities each 14 days for 76 of experiment

According to table 26, time did not significantly affect the pH of the soil, which slightly increased from week4 (pot experiment: 6.70 and field experiment: 6.68) to week8 (pot experiment: 6.8 and field experiment: 6.75) compared to the initial pH (week 0: 6.5) both in pot and field experiment while on week 10 (pot experiment: 7.01 and field experiment: 7.20) the value of the pH significantly increased. The percentage of the total nitrogen significantly increased with the time, the percentage increased from week2 (pot experiment 0.21% and field

experiment: 0.19%) to week 10 (pot experiment: 0.33% and field experiment: 0.38%) compared to the inital total nitrogen (week0: 0.18 %). Likewise, the concentration of the K significantly increased with the time, which also increased from week 2 (pot experiment: 6.13 mg/Kg and field experiment: 7.15) to week 10 (pot experiment: 10.01 mg/Kg and field experiment: 10.91 mg/Kg) in comparison with week0 (4.24 mg/Kg). In addition, there were significant differences in soil C/N ratios over the time. The value dropped from week 2 (pot experiment: 27.79 and field experiment: 28.55) to week 10 (pot experiment: 12.43 and field experiment: 1–2.18). Moreover, the concentrtion of the P and the percentage of the organic carbon significantly dropped with the time both in pot and field experiments.

**Table 26:** Effect of cassava peels composts on selected chemical properties of soils over ten-weeks

| | **Pot experiment** | | | | | |
|---|---|---|---|---|---|---|
| | **pH** | **Organic carbon (%)** | **Total nitrogen (%)** | **P(mg/Kg)** | **K (mg/Kg)** | **C/N** |
| week0 | 6.5±0.5$^{b}$ | 5.53±0.32$^{a}$ | 0.18±1.15$^{e}$ | 58±0.2$^{a}$ | 4.24±0.15$^{e}$ | 30.7±0.9$^{a}$ |
| **Week2** | 6.57±0.40$^{b}$ | 5.2±21.2$^{a}$ | 0.21±0.31$^{d}$ | 48.02±0.01$^{b}$ | 6.13±0.09$^{d}$ | 27.79±23.5$^{b}$ |
| **Week4** | 6.70±0.22$^{b}$ | 4.20±0.1$^{a}$ | 0.28±0.80$^{c}$ | 45.12±0.06$^{c}$ | 8.30±0.56$^{c}$ | 15.02±52.7$^{c}$ |
| **Week6** | 6.77±0.35$^{b}$ | 3.75±0.9$^{b}$ | 0.30±0.74$^{b}$ | 42.51±3.21$^{d}$ | 9.71±41.2$^{b}$ | 12.36±0.45$^{d}$ |
| **Week8** | 6.8±0.04$^{b}$ | 3.70±0.75$^{b}$ | 0.30±0.46$^{b}$ | 40.15±7.12$^{f}$ | 9.8±39.7$^{b}$ | 12.39±0.75$^{d}$ |
| **Week10** | 7.01±0.05$^{a}$ | 3.73±0.07$^{b}$ | 0.32±0.02$^{a}$ | 41.1±0.02$^{e}$ | 10.54±0.07$^{a}$ | 12.43±0.31$^{d}$ |
| | | | | | | |
| | **Field experiment** | | | | | |
| | **pH** | **Organic carbon (%)** | **Total nitrogen (%)** | **P(mg/Kg)** | **K (mg/Kg)** | **C/N** |
| **Week0** | 6.5±0.5$^{b}$ | 5.53±0.32$^{a}$ | 0.18±1.15$^{f}$ | 58±0.2$^{a}$ | 4.24±0.6$^{d}$ | 30.7±0.9$^{a}$ |
| **Week2** | 6.51±0.07$^{b}$ | 5.53±0.78$^{a}$ | 0.19±0.01$^{e}$ | 50.36±0.38$^{b}$ | 4.24±45.1$^{d}$ | 28.55±0.18$^{b}$ |
| **Week4** | 6.68±0.05$^{b}$ | 5.11±0.94$^{a}$ | 0.21±0.50$^{d}$ | 48.12±0.51$^{c}$ | 7.12±36.5$^{c}$ | 24.03±1.23$^{c}$ |
| **Week6** | 6.76±0.06$^{b}$ | 4.21±3.6$^{b}$ | 0.27±5.21$^{c}$ | 45.12±0.12$^{d}$ | 8.27±40.12$^{b}$ | 15.15±2.04$^{d}$ |
| **Week8** | 6.75±0.09$^{b}$ | 3.75±6.40$^{c}$ | 0.29±0.07$^{b}$ | 42.22±1.14$^{e}$ | 9.51±0.1$^{b}$ | 13.43±3.6$^{e}$ |
| **Week10** | 7.20±0.08$^{a}$ | 3.9±0.4$^{c}$ | 0.32±0.02$^{a}$ | 42.2±2.25$^{e}$ | 10.91±0.05$^{a}$ | 12.18±1.01$^{d}$ |

Means±SD followed by the same letter in a column are not significantly different at $P \leq 0.05$

### III.1.3.6.3.7 Some chemical properties of the soils after ten weeks of experiment

Data from table 27 shows that all the soils that were amended with CP1-B, CP1-E, CP1-S, CP2-B, CP2-E and CP2-S have significantly improved in terms of the chemical properties compared to conventional mineral fertiliwers and the controls.

The electrical conductivities (EC) were significantly higher from the soils amended with cassava peels compost. The values of the EC fluctuated from 108.9 µS/Cm to 109.1 µS/Cm in pot experiment and from 108.3 µS/Cm to 111.8 µS/Cm under field experiment, while the EC of those amended with mineral fertilizers fluctuated respectively from 80.2 µS/Cm to 89.1 µS/Cm in pot experiment and in field experiment from 79.8 µS/Cm to 81 µS/Cm. Likewise, the cation exchange capacity (CEC) of the same soils was significantly higher than the soils amended with NPK-B, NPK-E and NPK-S. The CEC values fluctuated respetively in pot experiment from 20.7 meq/100g to 23.9 meq/100g and under field experiment from 21.5 meq/100g to 24.5 meq/100g for the soil amended with CP1-B, CP1-E, CP1-S, CP2-B, CP2-E and CP2-S. The ECE of those amended with NPK-B, NPK-E and NPK-S fluctuated in pot experiment from 13.2 meq/100g to 15.6 meq/100g and under field experiment from 15.2 meq/100g to 16.6 meq/100g.

On the other hand, the concentration of Ca from the soil amended with organic fertilizers was significantly higher than those amended with the synthetic fertilizer. The concentration was respectively between 9.3 mg/Kg to 9.20 mg/Kg in pot experiment and 10.11 mg/Kg to 10.30 mg/Kg under field experiment for CP1-B, CP1-E, CP1-S, CP2-B, CP2-E and CP2-S plots. For the treatments NPK-B, NPK-E and NPK-S the concentration was between 0.03 mg/Kg and 0.06 mg/Kg in pot experiment while under field experiment it was between 0.06 mg/Kg to 0.09 mg/Kg. In addition, with the same treatments Mg and Fer were also significantly higher from the soils fertilized with CP1-B, CP1-E, CP1-S, CP2-B, CP2-E and CP2-S than those fertilized with NPK-B, NPK-E and NPK-S plots. The concentrations of the Mg and Fer from the soils treated with CP1-B, CP1-E, CP1-S, CP2-B, CP2-E and CP2-S were respectively in pot experiment: Mg ( between 2.81 mg/Kg and 3.88 mg/Kg) and Fer (between 41.2 mg/Kg and 47.1 mg/Kg). For those fertilized with chemical fertilizers the concentrations of the Mg and Fer were respectively in pot experiment: Mg (between 0.39 mg/Kg and 0.49 mg/Kg) and Fer (between 24.6 mg/Kg and 28.1 mg/Kg) while under field experiment– they were respectively Mg (between 0.39 mg/Kg and 0.51 mg/Kg) and Fer (between 24.6 mg/Kg and 28.1 mg/Kg).

However, the concentration of Ca, Zn and Cu in the soils fertilized with CP1-B, CP1-E, CP1-S, CP2-B, CP2-E and CP2-S fluctuated respectively in pot experiment (Ca : between 9.3 mg/Kg and 9.20 mg/Kg ; Zn : between 16.5 mg/Kg and 18.1 mg/Kg ; Cu : between 709.9 mg/Kg and 715.6 mg/Kg) and under field experiment (Ca : between 10.11 mg/Kg and 10.30 mg/Kg ; Zn : between 17.8 mg/Kg and 18.9 mg/Kg ; Cu : between 737.1 mg/Kg and 738.5 mg/Kg). The manganese concentration obtained from the soils fertilized respectively with organic fertilizers and chemical fertilizers was in pot experiment (between 301.1 and 310.4) and under field experiment (324.01 and 328.1) while from the soils fertilized with synthetic fertilizers accounted in pot experiment (between 415.6 mg/Kg and 420.5 mg/Kg ) and under field experiment ( between 439.7 mg/Kg and 441.1 mg/Kg).

**Table 27:** Effects of treatments on some soils chemical properties after ten weeks of experiment

| | Pot experiment | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **T** | **EC (µS/Cm)** | **Na (mg/Kg)** | **Ca (mg/Kg)** | **Mg (mg/Kg)** | **Fer (mg/Kg)** | **CEC ( meq/100g)** | **Zn (mg/Kg)** | **Mn (mg/Kg)** | **Cu(mg/Kg)** |
| **CP1-B** | 109.4± 0.3[a] | 1.72±0.04[a] | 9.18±0.02[a] | 2.89±0.04[b] | 44.1±0.04c | 20.8±0.02[c] | 16.5±0.7[c] | 306.2±0.5[e] | 715.6±0.35[b] |
| **CP1-E** | 108.9 ± 0.54[a] | 1.69±0.01[a] | 9.16±0.01[a] | 2.81±0.03[b] | 41.2±0.02f | 20.9±1.2[c] | 16.9±0.1[c] | 303.5±0.9[g] | 710.1±0.45[d] |
| **CP1-S** | 109.3 ± 0.7[a] | 1.72±0.12[a] | 9.16±0.03[a] | 2.84±0.02[b] | 43.5±0.12d | 20.7±0.012[c] | 18.1±0.14[a] | 301.1±0.41[h] | 709.9±0.38[d] |
| **CP2-B** | 108.9 ± 0.1[a] | 1.79±0.15[a] | 9.20±0.02[a] | 3.88±0.03[a] | 47.1±0.30a | 22.6±3.21[b] | 17.9±0.20[b] | 310.4±0.08[d] | 716.9±0.90[a] |
| **CP2-E** | 109.1 ± 0.2[a] | 1.61±0.20[a] | 9.14±0.01[a] | 3.85±0.08[a] | 42.0±2.1e | 23.9±0.08[a] | 16.9±0.51[c] | 304.9±0.38[f] | 711.6±0.25[c] |
| **CP2-S** | 109.2 ± 0.5[a] | 1.84±0.51[a] | 9.3±0.05[a] | 3.80±0.01[a] | 46.01±124b | 22.5±0.18[d] | 16.9±0.02[c] | 299.9.9±0.84[i] | 710.8±0.71[d] |
| **NPK-B** | 89.1 ± 0.6[b] | 1.25±0.03[a] | 0.04±0.07[c] | 0.49±0.01[a] | 23.12±1.1h | 13.2±1.27[f] | 12.9±0.8[d] | 420.5±23.1[a] | 708.2±1.51[e] |
| **NPK-E** | 80.2 ± 0.8[c] | 1.20±0.06[a] | 0.03±0.12[d] | 0.39±0.01[b] | 20.6±1.8j | 13.3±3.10[f] | 11.8±0.07[e] | 415.6±12.30[c] | 705.4±3.42[f] |
| **NPK-S** | 88.5 ± 0.9[b] | 1.32±0.09[a] | 0.06±0.11[b] | 0.49±0.011[a] | 26.5±2.7g | 15.6±0.09[e] | 18.1±0.17[a] | 419.4±0.61[b] | 709.7±0.64[d] |
| | **Field experiment** | | | | | | | | |
| **T** | **EC (µS/Cm)** | **Na(mg/Kg)** | **Ca(mg/Kg)** | **Mg (mg/Kg)** | **Fer (mg/Kg)** | **CEC ( meq/100g)** | **Znc (mg/Kg)** | **Mn (mg/Kg)** | **Cu(mg/Kg)** |
| **CP1-B** | 110.4±0.8[b] | 1.90±0.06[a] | 10.17±0.01[a] | 3.90±0.6[a] | 48.1±0.03[a] | 22.4±0.02[c] | 17.8±0.23[c] | 327.5±0.11[e] | 736.3±41.6[c] |
| **CP1-E** | 109.7±0.9[c] | 1.58±0.05[a] | 10.15±0.02[a] | 3.70±0.5[a] | 45.2±0.9[c] | 21.5±0.15[d] | 18.1±0.4[b] | 326.2±0.04[f] | 736±52.7[c] |
| **CP1-S** | 110.1±0.1[b] | 1.8±0.02[a] | 10.19±0.03[a] | 3.75±0.1[a] | 44.8±0.10[e] | 22.43±0.40[c] | 17.9±0.5[c] | 324.4±0.09[g] | 736.7±1.23[c] |
| **CP2-B** | 111.8±0.3[a] | 1.90±0.04[a] | 10.20±0.14[a] | 3.99±0.12a | 48.7±2.8[a] | 24.5±0.09[a] | 18.9±0.18[b] | 327.1±42.1[e] | 737.1±2.4[b] |
| **CP2-E** | 108.3±0.6[d] | 1.56±0.03[a] | 10.30±0.05[a] | 3.60±0.15[a]a | 46.3±1.14[b] | 23.9±0.3[b] | 18.9±0.5[b] | 324.01±36.5[g] | 738.2±0.08[a] |
| **CP2-S** | 107.5±0.8[e] | 1.96±0.08[a] | 10.11±0.04[a] | 3.75±0.01[a] | 46±1.30[b] | 22.5±0.04[c] | 18.8±1.2[b] | 328.1±54.4[d] | 738.5±0.1[a] |
| **NPK-B** | 79.8±0.2[h] | 1.30±0.01[a] | 0.08±0.14[c] | 0.45±0.005[c] | 26.4±0.07[g] | 15.2±0.9[f] | 13.2±3.4[d] | 441.1±23.12[a] | 710±0.8[e] |
| **NPK-E** | 80.5±0.5[e] | 1.34±0.06[a] | 0.06±0.08[d] | 0.39±0.004[c] | 24.6±0.08[h] | 15.3±0.2[f] | 12.8±1.12[e] | 440.1±3.54[b] | 712.1±0.9[d] |
| **NPK-S** | 81±0.7[f] | 1.31±0.0[a] | 0.09±0.09[b] | 0.51±0.1b | 28.1±0.10[f] | 16.6±0.8[e] | 19.5±0.42[a] | 439.7±60.1[c] | 710.4±0.44[e] |

Means±SD followed by the same letter in a column are not significantly different at $P < 0.05$

### III.1.3.6.3.8 Total mycoflora

As shown in Table 28, the populations of bacterial and fungal in the soil amended with composts (CP1-B, CP1-E, CP1-S, CP2-B, CP2-E and CP2-S) were significantly higher than the populations of the NPK-B, NPK-E and NPK-S plots. The bacterial populations in the soil amended with composts were respectively between 6.85 x $10^6$ c.f.u.g-1 of soil and 7.50 x$10^6$ c.f.u.g-1 of soil in pot experiment and under field experiment between 6.94 x $10^6$ c.f.u.g-1 of soil and 7.30 x $10^6$ c.f.u.g-1 of soil compared to the comtrols.

Likewise, the fungal population from the soils amended with CP1-B, CP1-E, CP1-S, CP2-B, CP2-E and CP2-S were also significantly higher than those from the soils fertilized with NPK-B, NPK-E and NPK-S. The concentrations of those fungi were respectively between 5.23 x $10^6$ c.f.u.g-1 of soil and 6.20 x $10^6$ c.f.u.g-1 of soil in pot experiment and under field experiment 5.90 x $10^6$ c.f.u.g-1 of soil and 6.70 x $10^6$ c.f.u.g-1 of soil.

**Table 28: Effect of treatments on microbial population of the amended soils**

| | **Microbial biomass (.$10^6$ c.f.u.g-1 soil)** | | | |
|---|---|---|---|---|
| | **Pot experiment** | | **Field experiment** | |
| **Treatments** | **Fungi** | **Bacteria** | **Fungi** | **Bacteria** |
| **CP1-B** | 5.91±4.45$^b$ | 6.99±7.5$^b$ | 6.10±0.48$^a$ | 7.12±1.15$^a$ |
| **CP1-E** | 6.20±0.75$^a$ | 7.10±2.1$^a$ | 6.40±0.21$^a$ | 6.95±0.5$^b$ |
| **CP1-S** | 5.89±2.54$^b$ | 6.85±0.4$^b$ | 5.99±0.51$^a$ | 6.94±0.57$^b$ |
| **CP2-B** | 6.10±0.9$^a$ | 7.50±6.9$^a$ | 6.68±0.29$^a$ | 7.10±0.08$^a$ |
| **CP2-E** | 5.23±0.04$^b$ | 7.25±0.73$^a$ | 5.90±0.35$^a$ | 6.99±0.01$^b$ |
| **CP2-S** | 5.99±0.1$^b$ | 6.89±0.64$^b$ | 6.70±0.12$^a$ | 7.30±3.25$^a$ |
| **NPK-B** | 3.04±5.54$^c$ | 3.12±0.09$^c$ | 3.12±0.04$^b$ | 3.24±2.51$^c$ |
| **NPK-E** | 3.09±0.08$^c$ | 3.05±1.18$^c$ | 3.20±0.01$^b$ | 3.15±0.1$^c$ |
| **NPK-S** | 2.99±0.19$^c$ | 3.12±12.7$^c$ | 3.19±0.45$^b$ | 3.16±0.07$^c$ |
| **C-B** | 3.60±0.02$^c$ | 3.80±0.04$^c$ | 3.73±0.03$^b$ | 3.95±0.05$^c$ |
| **C-E** | 3.50±0.01$^c$ | 3.90±0.05$^c$ | 3.74±0.04$^b$ | 3.85±0.32$^c$ |
| **C-S** | 3.59±0.15$^c$ | 3.79±0.01$^c$ | 3.72±0.32$^b$ | 3.90±1.50$^c$ |

Means±SD followed by the same letter in a column are not significantly different at $P < 0.05$

### III.1.3.6.3.9 Quality of fruits and soil collected from farmers field at Foumbot

Table 29 showed that the soil collected from famers field had the pH (5.4); electrical conductivity (80.6 µS.cm$^{-1}$ ) ; total nitrogen ( 0.12% ); C/N ration ( 24.5) significantly lower compared to the experimental soil (table 15 ). The same soil presented the highest value in terms of organic carbon ( 2.88%); phosphorus( 10.04 mg.kg$^{-1}$); potassium ( 78.1 mg.kg$^{-1}$) ; sodium ( 11.7 mg.kg$^{-1}$); magnesium ( 290.5); calcium (310 mg.kg$^{-1}$) ; Fer ( 2350 mg.kg$^{-1}$) and manganese (0.62 g.kg-1 ). The mineral content such as Mg (12.22 mg/100g); K(78.1 mg/100g); Na (174.91 mg/100g) ; Cu (59.2 mg/100g) and Zn (189.20 mg/100g) including the Na/K(1.70) and Ca/P(1.89) ratios of sweet pepper fruits cultivated by farmers was significantly lower than the mineral content of fruits harvested from CP1-B and CP2-B ( table 24). Farmers' fruits also presented the lowest value of total sugar (3.99 mg/100g); protein (0.70 mg/100g) and total ash (0.77 g/100g) compared with the values obtained from CP1-B and CP2-B. The percentage of total lipid (12.08 %) and crude fiber (12.21%) were significantly lower. The value of the pH (5.49) and the water content (96.57%) of farmers' fruits was significantly higher compared to the organic fruits (table 23). Farmers' fruits presented the lowest concentration in terms of vitamin C (89.95 mg/100g); polyphenol (29.17 mg/100g) and flavonoid (89.88 mg/100g) compared with fruits harvested from CP1-B and CP2-B. In addition, the antioxidant potential ( DPPH: 70.8%; FRAP: 20.89 g/100g and TAC: 98.90 g/100g) of sweet pepper fruits collected from Foumbot was also significantly lower compared with the values obtained from CP1-B and CP2-B plots. On the contrary, their pesticide residues content (0.199 mg/kg) was significantly higher compared with the organic sweet pepper fruits, which did not present any pesticide residue. The same concentration of pesticide residues was also observed from sweet pepper fruits harvested from NPK-S plots.

**Table 29**: Quality of farmers' fruits and some physicochemical properties of the soil collected from Foumbot

| Parameters | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **pH** | **EC ($\mu S.cm^{-1}$)** | **Organic carbon (%)** | **Total N (%)** | **C/N ratio** | **P (mg.kg-1)** | **K (mg.kg-1)** | **Na (mg.kg-1)** | **Mg (mg.kg-1)** | **Ca (mg.kg-1)** | **Cu (g.kg-1)** | **Fe (mg.kg-1)** | **Mn (g.kg-1)** | **Zn (g.kg-1)** |
| **Farmer soil** | 5.4±0.1 | 80.6±0.8 | 2.88±0.45 | 0.12±1.15 | 24.5±0.9 | 10.04±0.2 | 78.1±0.01 | 11.7±0.34 | 290.5±0.5 | 310±0.1 | 0.52±2.4 | 2350±0.5 | 0.62±0.4 | 0.11±0.8 |

| Parameters | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Ca (mg/100g)** | **P(mg/100g)** | **Mg(mg/100g)** | **K(mg/100g)** | **Na(mg/100g)** | **Cu(mg/100g)** | **Zn(mg/100g)** | **Mn(mg/100g)** | **Na/K** | **Ca/P** |
| **Farmers fruits** | 81,08±4,6 | 42.9±0.05 | 12.22±0.01 | 102.89±2.51 | 174.91±20.14 | 59.2±0.1 | 189.20±0.01 | 200.3±0.20 | 1.70±0.2 | 1.89±0.49 |

| Parameters | | | | | | | |
|---|---|---|---|---|---|---|---|
| | **pH** | **Total sugar (mg/100g)** | **Total lipids (%)** | **Crude fiber ( %)** | **water content ( %)** | **Protein (g/100g)** | **total ash (g/100g)** |
| **Farmers fruits** | 5,49 ± 0,02 | 3.99±0.1 | 12.08±0.07 | 12.21±0.01 | 96.57±0.05 | 0.70±0.01 | 0.77±0.06 |

| Parameters | | | | | | | |
|---|---|---|---|---|---|---|---|
| | **Vitamin C (mg/100g of FM)** | **Polyphenol (mg/100g)** | **Flavonoid (mg/100g)** | **DPPH (%)** | **FRAP (g/100g)** | **TAC (g/100g)** | **Pesticide residues (mg/kg)** |
| **Farmers fruits** | 89.95 ± 0,70 | 29.17±1.17 | 89,88 ± 0,12 | 70.8±0.05 | 20.89±0.5 | 98.90±0.34 | 0.199±0.004 |

Means±SD followed by the same letter in a column are not significantly different at P < 0.0

## III.2 Discussion

### III.2.1 Cultural practices and diseases management survey of sweet pepper at the locality of Foumbot, west region of Cameroon

This section aimed to survey the cultural practices and diseases management of sweet pepper at the locality of Foumbot. From the survey, the data showed that the sweet pepper producers were mostly men (80%) with women representing only 20% of producers. A similar result was also obtained by (Sopkoutie *et al*., 2021), regarding tomato producers in Foumbot, who showed that the studied population consisted of 70 % men and only 30% women. This was not the case of (Mfopou *et al.*, 2017) in the centre region of Cameroon where the percentage of men was equal to that of women. The different observed between the number of men and women farmers in the West Region of Cameroon might be due to the lack of women dynamism who do not generally conduct their activities out of their homes. Sweet pepper farming is mostly done at Foumbot by the farmers' age between 18 to 48 years old, which is an indicator of the robustness of the activity. This age group of sweet pepper growers was also observed by Mbangari *et al*., 2020 and Sonchieu *et al*., 2018. The greatest level of experience (10 to 30 years) observed from the sampled farmers might confirm that the locality of Foumbot is the major region of sweet pepper cultivation. Tarla *et al*., in 2015 reported that Foumbot is the major vegetable growing such as sweet pepper and tomatoes.

The major varieties of sweet pepper seeds cultivated in Foumbot were Yelo wonder (55% of the surveyed farmers) and Simba (45% of the surveyed farmers). This could be due to the fact that the Yelo wonder variety is cheaper than the Simba variety. Simba variety is also resistant to many diseases. Most of the sweet pepper cultivators prefer growing sweet pepper during the rainy season than the dry season. The reasons behind the choice of growing season could be because during the rainy season, water is available and insect pests are reduced. During the dry season, diseases are not serious and cost of sweet pepper production is lower.

The different frequencies of soil amendment and pesticides used obtained in this study might be led to the lack of training concerning the cultivation of sweet pepper and the level of education of the respondents (Nguemo *et al*., 2019).

The described and observed symptoms of sweet pepper diseases at the locality of Foumbot showed that diseases and pests are important constraints to sweet pepper production in the west region of Cameroon (Nguemo *et al*., 2019). The major diseases and pests that led with the

cultivation of sweet pepper in Foumbot were (1) diseases: Mildew, cercospora leaf spot, phytopthora blight, fusarium wilt, anthracnose, ripe rot, tobacco mosaic virus, cucumber mosaic virus, and gal formations; (2) pests: flee beetles, cutworms, aphids, vegetable weevil, caterpillars, grasshoppers, pepper maggots and leaf miners. The same major diseases and pests had also been reported by (Lin *et al*., 2020; Amuoh, C. N, 2011). This could explain the overused of chemical phytosanitaries such as insecticides (cypermitrin; mabeb; lambda-cyhalothrine; aldicarb; acetamipride; ethoprop) and fungicides (metalaxyl+mancozeb; mancozeb and maneb).

The most commonly used chemical phytosanitaries were respectively, insecticides (Lambda-cyhalothrine + Acétamipride and Cypermethrine), and fungicides (Metalaxyl and Mncozeb), (Fai *et al*., 2019; Nguemo *et al.,* 2019; Matthews *et al*., 2003). Pouokam *et al*., 2017 reported on the use of these classes of chemicals. However, the number of pesticides listed could be evidence of serious pest problems and difficulties in control, which prompt growers to try several formulations. It might also be an indication that sweet pepper farmers are not using appropriate pesticides (Fai *et al.,* 2019; Nguemo *et al*., 2019). In addition, application means such as target plant part, time, frequency and doses could be incorrect due to the lack of knowledges (Nguemo *et al*., 2019). Another reason may be pest resistance to pesticides or the lack of means to purchase pesticides is the highest evidence of pest and disease outbreaks (Tabashnik *et al*., 2014; Abang *et al*., 2013). The abundant usage of chemical phytosanitaries by the sample growers testifies to the favorable environment for sweet pepper plant diseases development and their effectiveness.

The high incidence and severity of the diseases during the cultivation of sweet pepper might be due to the lack of seeds treatment before seeding and use of non-specific phytosanitaries. This could also be explained by the fact that the same active ingredients of the above phytosanitaries have been used since decades in various mixtures in which concentrations are often modified or set as a combination of more than one active molecule (Sonchieu *et al*., 2018). It has been reported from the same area of Cameroon that, the choice of a pesticide depends on the availability instead of the specificity of a crop pathogen.

The survey done by Sonchieu *et al*., 2018 also showed that the misuse of pesticide applicators in Foumbot agricultural area, lead to the increasing of vegetable diseases and resistance mechanisms in pathogens. In 2020, Lengai *et al.,* also found that the utilization of pesticides lead to the resistance mechanisms in pathogens. In addition, the resistance of those pathogens

might be because most of the sampled cultivators did not either finish the secondary school or attain the university level and do not have technical assistance from trained technicians for them to overcome sweet pepper diseases. (FAOSTAT, 2014; Pouokam *et al*., 2017).

The few numbers of tons harvested by sweet pepper cultivators from the West Region of Cameroon (Foumbot) could be led to the above diseases and the lack of farmers' means respectively in soil amendment, pest and disease management.

### III.2.2 Composting process

This part aimed to evaluate the quality of cassava peels compost. Based on the results, the lack of odours noticed respectively during the composting process and at the end of the process might be due to the absence of some volatile compounds such as $NH_3$ (Zhang *et al*., 2018) organic acids, and some of the sulfur-containing compounds and the increased aeration that took place during the composting process. (Zhang *et al*., 2018). Besides, it may be the result of the absence of those intermediate compounds that had been decomposed during the thermophile phase of composting (Zhang *et al*., 2018). Moreover, that lack of odour should be also explained by the acidity of the compost piles pH, which was (5.7). It could also be explained by the initial value of cassava peels C/N ration (30.13), which did not allow the underutilization of N, during which the excess is usually lost to the atmosphere as ammonia or nitrous oxide. That is in accordance with the findings of (Misra *et al*., 2003) and (Kassa *et al*., 2011) who showed that a C: N ratio of less than 20:1 leads to underutilization of N and the excess may be lost to the atmosphere as ammonia or nitrous oxide.

#### III.2.2.1 Physical and chemical properties

The salinity of a compost is measured by its electrical conductivity, which greatly depends on the nutrient content of the compost and determines the phytotoxicity of a compost. Therefore, the increase of EC regarding the amount of cassava peels, which was composted, could be explained by the process of organic matter mineralisation, which always takes place during the composting process (Azim *et al*., 2018 and Francou *et al*., 2003). That increase might also be the result of the maturation phase, which is the last phase of the process of composting, during which there is a production of organic acids and soluble salt. Moreover, it could also be explained by the slight amount of Mg2+; Ca2+; K+ and Na+ in the produced composts. (Francou *et al*., 2003, Bougnom *et al.,* 2020 and Avnimelech *et al.,* 1996). As a result, a great amount of cassava peels might increase the salinity of the final product that might cause osmotic problems and affects water intake ability (Francou *et al*., 2003). However, the value of the

electrical conductivity of each produced compost was below the value that might cause a toxical effect on plants (3,7 à 8,8 mS/cm) (Wu *et al*., 2000).

The absence of Mn and Cu from the produced composts could be explained by their absence from the composted cassava peels.

The slight increase of pH from the obtained composts (C1, C2, C3, and C4) could be explained by the presence of a thermophilic phase in which there is the degradation of organic acids, produced during the acidophilic phase, which allows a phenomenon of alkalization of the compost, which is increased by the mineralization of the soil's nitrogen (Francou *et al*., 2003, Larbi *et al*., 2006, Xu *et al*., 2019 and Wu *et al*., 2020). That increase in pH may be also attributed to the lack of production of some organic acids (Francou *et al*., 2003 and Bougnom *et al*., 2020). It could also be the lack of $CO_2$ mineralization of organic material (Bougnom *et al*., 2018).

The increase of the total nitrogen from C2, C3, and C4 at the end of the process of composting could be the result of two main reactions that took place during the process: the reaction of mineralization and nitrification (Cáceres *et al.,* 2018), during which there is the production of $NH_4^+$ and $NO_3^+$. It might also be due to respectively the lack of $NH_3$ volatilization and the absence of three other reactions (incomplete denitrification, complete denitrification) during which there is the formation of $N_2O$ and $N_2$ that can be released into the atmosphere (Usmani *et al.,* 2019). Moreover, the increase of the total nitrogen from C2, C3, and C4 could also be explained by the fact that, under the pH conditionss (less than 8.4), (Cáceres *et al*., 2017), the NH3-N form is difficult to be volatilized to the gas form and lost (Usmani *et al.,* 2019).

The decrease of P in the different composts could be explained by the fact that the composting may affect the distribution of P fractions, and the lack of phosphate solubilizing microbes that might solubilize insoluble P composts (Francou *et al.*, 2003). It might also result in the lower presence of microbial activity related to organic acids production lead to the solubilization of precipitated inorganic P (Francou *et al*., 2003 and Cáceres *et al*., 2017).

The drop of C/N rations at the end of the composting process could be the result of the lack of nitrogen volatilisation (i.e. increasing nitrogen content) (Francou *et al*., 2003 and Chowdhury *et al*., 2013). It may be also due to the release of the carbon in the form of $CO_2$, and it would imply the level of humification of the organic matter (Chowdhury *et al*., 2013). Studies done previously, have indicated that a C/N ratio between 10 and 21 at the end of composting is an

indicator of compost maturity (Francou *et al*., 2003 and Chowdhury *et al*., 2013). In this study, the composts produced meet this criterion.

One of the most commonly used and sensitive biological indicators for assessing the phytotoxicity and maturity of compost products is the value of the GI (Francou *et al*., 2003 and Liu *et al*., 2018). The results obtained from the phytotoxicity test demonstrated that the composts had GIs ≥ 80%. Those results showed that the produced composts were mature and devoid of any toxic effect. Those results are in accordance with the result obtained by (DeLuca *et al*., 1997, Bohacz *et al*., 2018, Luo *et al*., 2018 , Jiang *et al*., 2018 and Liu *et al.,* 2019) and (Francou *et al*.,2003), who showed that GI values of 80% are indicative of mature compost with no phytotoxic effect.

### III.2.2.2 Microbial biomass

The increasing quantity of cassava peels had positive effects on bacterial and fungal populations because it did not impair or change the imbalance that is usually observed at the end of the composting process in which the proportion of fungi increases, while bacterial numbers decline. (de Bertoldi *et al*., 1983). That increase of fungi population and decrease of the bacterial population could be due to the fact that during the maturation phase, compounds that are not further degradable, such as lignin–humus complexes and cellulose, are formed and become predominant (de Bertoldi *et al*., 1983 and Jiang *et al*., 2018 ). Such kind of compounds is much more degradable by the fungal population than bacterial population (Jiang *et al.,* 2018). It may also be explained by the water potential decreases, which is an advantage for fungi. On the other hand, the lack of significant difference, respectively in between the proportion of fungi and bacterial biomass, observed from the produced composts could be due to the relative salt concentrations (EC) that have been noticed. (Muscolo *et al.,* 2018, Liu *et al.,* 2019 and Gómez-Silván *et al.,* 2020). Therefore the important presence of this total microflora would reflect the maturity and eco-compatibility of the composts (Francou *et al*., 2003).

### III.2.3 Pot and field experiments

The aim of this section was to study the effect of the combined use of acqueous extract of *Ocimum gratissimum* leaves and the composts produced on the productivity of sweet pepper and compared the shelf life of sweet peppers'fruits obtained from soil amended by bio-inputs and a conventional fertilizer. In addition, to evaluate the treatments effect on the organoleptic, nutritional, biological quality and pesticide residues of the obtained fruits.

### III.2.3.1 Vegetative Growth charateristics

Overall, treatments CP1-B; CP1-E; CP1-S; CP2-B; CP2-E and CP2-S significantly increased the vegetative growth of plants compared to NPK-B; NPK-E and NPK-S plots. The improvement in vegetative growth of organic plants in this study might be the consequence of an increase in N supply that led to the utilization of carbohydrates and allowed the formation of protoplasm and more cells, (Ayodele *et al.,* 2015). The highest number of leaves, branches, plant height and crown diameter obtained from the plant treated with CP1-B, CP1-E, CP1-S, CP2-B, CP2-E and CP2-S plots both in pot and field conditions, might be due to the better physicochemical properties of the compost, which contained micro nutrients such as Calcium, Magnesium and Zinc ; etc, and it richness in organic matter which would have improved the physico-chemical properties of the soil and therefore resulted in better sweet plants development. This is in line with the results obtained respectively by Pariari *et al*., 2013, Shiva *et al*., 2015, Adhikari *et al*., 2016 and Tajungsola *et al.,* in 2017. This can also be the result of the improved nutrition of the treated plants through the development of root system, which accelerated the growth and the accumulation of biomass of the photosynthesizing organ (Małgorzata Beroval *et al.,* 2010). In addition, It could also be explained by the presence of growth regulators, because composts might contained a suitable concentration of different growth regulators such as indole acetic acid and cytokinin which significantly improved plant growth (Abd El-Rheem Kh. *et al.,* 2019 ) or the increased microbial activity after cassava peels compost addition could have also influenced the root environment and plant growth through the production of plant growth hormones, including indole acetic acid, gibberellins, and cytokinins, by a wide variety of rhizosphere microorganisms. Additionally, cassava peels compost might contain significant amounts of humic substances, which is expected to have an important and positive impact on soil fertility (Fernandez *et al.,* 2004).The presence of humic substances in the cassava peels manure may also explain the improvement in growth and fruit yield of the organic sweet peppers in the present work. (Immaculada, 2010). It might also be due to the fact that application of compost provided adequate Nitrogen which is associated with high photo synthetic activity and vigorous vegetative growth (Suresh Ghimire *et al.,* 2013 and Tajungsola Jamir *et al*., 2017). This results are also in accordance with the findings of Kekere *et al.,* (2020) who found a significant increase in plant height, number of leaves, number of fruits, number of flowers and total fruit weight of plants grown in soil mixed with organic fertilizer.

Furthermore, those vegetative growth results could be due to the presence of hormones that enhance plant growth in aqueous extract of *Ocimum gratissimum* leaves such as auxin, gibberellins, cytokinins, salicylic acid (Pariari and Khan, 2013, Shiva *et al.,* 2015 ; Adhikari *et al.,* 2016). It may be also due to the presence of the primary metabolites in aqueous extract of *Ocimum gratissimum* leaves such as carbohydrates, proteins and amino acids which could promote plant growth.

The earliness in flowering observed from the plant cultivated in the soils amended with cassava peels compost and sprayed with *aqueous extract of Ocimum gratissimum leaves* could be attributed due to (1) the faster enhancement of vegetative growth and storing sufficient reserved food materials for differentiation of buds into flower buds including some plant growth promoters such as auxins and gibberellic acid which induces flowering. Similar results were obtained by Leela *et al*., 2010 and Tajungsola Jamir *et al*., (2017) ; (2) the translocation of nutrients to the aerial parts of the plant and the solubilisation effect of plant nutrients by addition of cassava peels compost to increase uptake of nitrogen, phosphorus and potassium and resulted in maximum number of flowers per plant in *capsicum,* this is in accordance with the results obtained by Kumar *et al*., (2013), Shiva *et al*., (2015), Vikas Kumar *et al*., (2016) and Tajungsola Jamir *et al*., (2017). In addition, the earliness in flowering observed might also be due to the promoting influence of aqueous extract of *Ocimum gratissimum* leaves on pepper leaves area and efficiency of the photosynthesis process resulting in an increase in the percentage of the total soluble substances. Similar results were also obtained by Jensen, in 2004 and and Tajungsola Jamir *et al.,* (2017) after spraying seaweed extracts on pepper leaf area. Moreover, it could be due to the presence of ascorbic acid (antioxidant) which has auxinic action and owns a synergistic effect on flowering and production (Tajungsola *et al*., 2017).

**III.2.3.2 Assessment of the incidence and severity of diseases.**

CP1-B and CP2-B had respectively the lowest percentage of the wilt incidence and severity. The lowest percentage of disease incidence and severity observed from the sweet pepper plants sprayed with aqueous extract of *Ocimum gratissimum* leaves and grew in the soils amended with cassava peels compost (CP1-B and CP2-B) both under control and field conditions could be explained by the presence of bioactive secondary metabolites in leaves extracts of *ocimum gratissimum* which protected sweet pepper plants against biotic and abiotic stress. These secondary metabolites, including enzymes and proteins, might have allowed plants to fight against diseases, extreme climatic conditionss and to repel attacks by pests or repair damage caused by insects or a phytopathogen (Debbab, 2014 ; Avoseh, 2015). In 1986 and 2001, Oluma

*et al.,* and Tripathi *et al* respectively stated that the extracts of *Ocimum gratissimum* have been used as insect repel to eliminate Pythium aphanidermatum causing mill dew in plants and reduce the attack of Sclerotium rolfusil on cowpea.

It might also be due to, according to Nguefack *et al*., (2007), the high richness of *ocimum gratissimum* leaves extract with active phenolic compounds such as thymol, which according to Beuchat and Golden ,1989, has a broad antimicrobial spectrum. Those secondary mtabolites compounds could act either synergistically or antagonistically for a great inhibitory activity. Furthermore, it could be due to the highest concentration of vitamins (vitamin C) in sweet pepper plant, sprayed with the extracts of *ocimum gratissimum* , with their anti oxidative properties which play an important role in plant defense against oxidative stress inducing by surfactants ( Ghurbat, 2013). Moreover, It could be explained by either a large group of fungi and bacteria sourced by cassava peels compost that might affect multiple pathogens activating general suppression mechanisms (Antibiosis and Hyperparasitism) or a restricted group of microbiota causes a specific disease suppression against one or few pathogen groups (Ugo De Corato *et al.,* 2018) and the sum of the biological activities of the overall filamentous fungi and bacteria of the composts able to support suppression of Fusarium wilt (Borrero *et al.,* 2004 **).** In additon, cassava peels compost might have a varied pool of antagonistic microbiota (*Trichoderma, Aspergillus, Pseudomonas*, *Bacillus* and *actinomycetes*) which might have contributed to suppress wilt of sweet pepper. (Bonanomi *et al.,* 2010), through the production of antibiotics and hyperparasitism mechanism (Kyselková and Moënne-Loccoz, 2012). This is in line with the resuts obtained by Hoitink and Fahy, (1986), Serra-Wittling *et al*. (1996), Yogev *et al*., (2011) and C.M. Mehta *et al.,* (2013) who respectively reported that (1) various types of composts produced from agricultural and forestry wastes could be used in the suppression of soil-borne plant pathogens, especially those belonging to the genera *Rhizoctonia, Pythium, Fusarium and Phytophthora*, (2) soil amended with solid waste compost significantly reduced Fusarium wilt, (3) organic farming practices and especially compost application, may lead to some reduction of the problems caused by *F. oxysporum* f. sp and other microorganism and (4) composts richness in microogonisms such as Pseudomonas and Bacillus are well known for their antibiotic production properties, and for their biocontrol of several crop diseases. In addition, organic matter protects crops against pathogens and saprophytic through increasing parasitism and antibiosis (Jamir *et al.,* 2017). Moreover, biofertilizer offers microbial diversity in rhizosphere zone, provides defense against pathogen attack, plant growth promoting bacteria and antibiotics (Parasad *et al.,* 2017).

### III.2.3.3 Yield caracteristics

Fruits harvested from the plants grew with treatments CP1-B, CP1-E, CP1-S, CP2-B, CP2-E and CP2-S exhibited the number of fruits per plant; fruit length; fruits diameter; and fruit weight significantly higher than those harvesyed from the plots treated with NPK-B, NPK-E and NPK-S under controlled and field conditions. This could be, respectively, due to the compost application that increased the population of beneficial microorganisms in soil and the increased intensity of the processes in which they are involved, which in turn, preconditionss better plant nutrition (Tringovska and Kanazirska, 2003; Berova *et al*., 2010) and the production of more number of flowers, a higher percentage of fruit set and reduced shedding of flowers and fruits resulted in increased fruits. Similar results were obtained by (Tripathy and Maity, 2011). Besides, it may be due to the application of cassava peels compost leading to increase uptake of N, P and K. The same results were also stated by Pariari and Khan, 2013. Moreover, cassava peels compost also contained micronutrients and it increased microbial activity, which might have improved the availability of macro and micronutrients to the plants. It might also act as a chelating agent and regulates the availability of metabolic micro-nutrients to plants. (Bhandari *et al*., 2015).

The increasing fruit weight could be the result of compost application which is a good source of a stable organic matter which acts as a storehouse of all plant nutrients including trace elements that might have been released gradually. Therefore, this contributed towards the balanced nutrition of sweet pepper plants resulting in maximum fruit weight. The same results were, obtained by Gopinath *et al*., (2011), Pariari and Khan, (2013), Bhandari et al., (2015), and Adhikari *et al*., (2016). Furthermore, the increase in fruit weight and length might also be due to the action of Ocimum gratissimum aqueous extracts which may have enhanced the leaves numbers, leaf area and dry weight and consequently the physiological activities as photosynthesis and plant nutrition provision (Al-Saaberi, 2005).

Treatments CP1-B and CP2-B increased sweet pepper yield respectively by 66% and 93% in pot and by 125% and 187% under field conditions. And the maximum number of fruits yield per treatment and fruits diameter, was recorded respectively with CP2-B and CP1-B. This could be due to the foliar spraying of *O. gratissimum* aqueous extract, which might have stimulated the production of ascorbic acid in sweet pepper plants, which in turn improved the physical characteristics of pepper plants. This is in accordance with the results obtained by Wassel *et al*., (2007) who stated that the increase of yield and fruits might be due to the auxinic action of ascorbic acid on enhancing the cell division and elongation, therefore, reflected positively on

the leaf area. Moreover, this effect could be attributed to that cassava peels compost increase supply of phosphorus and potassium to the soil, which improves the soil fertility. In addition, cassava peels compost has much higher nitrogen and humic acid which gives strong plant growth therefore, fruit yield. Similar results were obtained by Ghoname *et al*., (2005) and El-Bassiony *et al*., (2010). Its positive effect on plant growth may be for its containin Azotobacter and Azospirillum, which produced adequate amounts of Indole-3-acetic acid (IAA) and cytokinin, thus increased the surface area per unit of root length and responsible for root hair branching with an eventual increase in uptake of nutrients from the soil (Jagnow *et al*., 1991). In 2008, Medina-Lara *et al.*, stated that the highest fruit set from inorganic sweet pepper plants could be explained by the effect on initial stimulation of the flowering process via the inorganic nitrogen release by the application of organic fertilizers, which leads to higher fruit formation as well as fruit yield.

### III.2.3.4 Organoleptic properties

Fruits harvested from treatments CP1-B and CP2-B were more acceptable than the fruits harvested from the plots treated with CP1-E; CP2-E CP1-S CP2-S NPK-B NPK-E and NPK-S both under controlled and field conditions. The highest acceptability of from sweet pepper fruits harvested from the treatments CP1-B and CP2-B could be due to their richness in secondary metabolites (polyphenolic, terpenoid compounds; etc.), which serve to increase their attractivenes as well as organoleptic characteristics, such as aroma, color, tast, shape and appearence (; Fraser and Chapple, 2011; Hassan and Mathesius, 2012, Delphine M. Pott *et al.*, 2019). In addition, it could be explained by the presense of volatile and non-volatile compounds in sweet pepper fruits (Eggink, *et al.*, 2011) more specificaly the presence of phenylpropanoid and terpenoid volatiles, primary metabolites including carbohydrates, fatty acids, and amino acids, which are also the direct precursors of many compounds that significantly contribute to the fruit organoleptic characteristics (Delphine *et al.*, 2019).

### III.2.3.5 Effect of treatments on postharvest conservation of sweet pepper fruits

Sweet pepper fruits harvested from the plants grew with treatments CP1-B and CP2-B had a long shelf life, which accounted respectively 90 days when stored at 4 $^0$C and 26 days when stored in an ambiant temperature, significantly higher than those harvested from the plants cultivated with NPK-S (17 days at 4 $^0$C and 11 days ambiant temperature) both in pot and field experiments. The longest shelf life obtained from the fruits harvested from the plots treated

with CP1-B and CP2-B might be due to the fact that those fruits had high antioxidant content and bioactive molecules, which, according to Debbab *et al*., 2014, delayed the onset of post-harvest infections. In addition, it could also due to their low water concentration and water activity as well as the value of their pH that did not allow the development of microorganisms and spoilage process of fruits (Sandulachi, 2016 and Inc, 2014).

### III.2.3.6 Effect of treatments on the pH of sweet peppers fruits

The low pH values (4.20 - 4.54) of fruits obtained from plants cultivated with CP1-B, CP1-E, CP1-S, CP2-B, CP2-E and CP2-S both in pot and field experiments could be the result of **t**he cassava peels compost application which provided the organic C that may have been used for the production of organic acids like citric acid ( the primary organic acid found in most fruits. ) and malic acid, which are responsible for the acidity of fruit (Mitchell *et al.,* 2007). These results are in accordance with the previous works run respectively by Wang and Lin, 2002 and Aminifard *et al*., (2013) who argued that organic fertilizers increased the levels of organic acids in pepper fruits. Also, Wang and Lin, 2002 showed that fruits with low pH value, grown in organic fertilizers, indicate more citric acid, which is responsible for the low pH and beneficial for human consumption. Moreover, it could be due to the nitrification of ammonium nitrogen (Vasconcelos *et al* ., 2004 ).

### III.2.3.7 Macronutrients of sweet pepper fruits

#### III.2.3.7.1 Water content, Protein content and total ash content.

The application of CP1-B, CP1-E, CP1-S, CP2-B, CP2-E and CP2-S was found to significantly decrease fruits water content (a constituent of food, which affects food safety, stability, quality and physical properties) as compared with the treatments NPK-B, NPK-E and NPK-S. This is in line with the results reported on sweet pepper by Abu-zahra *et al.,* (2012), who stated that the application of organic fertilizers decreases the water content of the fruits, which reflected in increasing fruit dry matter, compared to the conventional treatment which produced the highest water content. Besides, the low levels of water contents in those sweet pepper fruits could be attributed to their richness in fibrous which is slightly woody (Ekwere *et al*., 2016).

CP1-B (pot experiments: 0.85 g/100g and field experiments: 0.88 g/100g) and CP2-B (pot experiments: 0.97 g/100g and field experiments: 0.98 g/100g) held the highest concentration of proteins. This might be the result of compost application which might promote plant growth by increasing nitrogen availability, which role is to promote protein synthesis and increasing

the meristematic activity. This is in line with Kanwar and Paliyal, (2002) and Mohammed *et al*., (2016), who demonstrated that the application of compost led to the increase protein content of sweet pepper fruits. Also, the increase in protein content could be attributed to the increase in the number of leaves which would have increased photosynthetic surfaces and the current photosynthates produced would have enhanced the physiological activities leading to the production of more assimilates used to significantly increased protein content (Alabi *et al*., 2006). Moreover, Alabi *et al*., (2006) have also reported that the increase in protein content in pepper fruits lead to an increase of nitrogen fertilizers.

The increase in total ash content of the sweet pepper fruits harvested from the pepper plants grown with cassava peels compost could be due to the application of cassava peels compost that released organic minerals and inorganic minerals in the soil (Ihemeje *et al*., 2013 and Akinyem *et al.,* 2018).This is in line with the result obtained by Guilherme *et al.,* 2020 who reported that the ash content of the sweet pepper fruits obtained from the organic agriculture was found significantly higher than those obtained from the conventional agriculture.

**III.2.3.7.2 Total sugar content, total lipids and crude fibre of sweet pepper fruits**

Based on the results, treatments CP1-B; CP1-E; CP1-S; CP2-B; CP2-E and CP2-S exhibited the highest concentration of the total sugar content. The increase in total sugar content obtained from the sweet pepper fruits harvested from the plants grown with those treatmets might be due to the increase of the microorganisms in the soil that might have had a positive effect in converting the unavailable forms of nutrient elements to available forms. Those microorganisms could have produce growth-promoting substances resulting in more efficient absorption of nutrients, which are main components of photosynthetic pigments and consequently the carbohydrate (Gomaa and Abou-Aly, 2001 and Mohammed *et al.,* 2013). These results are in line with those obtained by (Mohammad *et al* ., 2013 ). Copetta, *et al.,* (2011), came to the same results and reported that compost application improved carbohydrate content. In addition, the foliar application of *O. gratissimum* aqueous extract might have induced the production of secondary metabolites (phenolic and terpenoid compounds) in fruits to protect them against biotic and abiotic stresses, therefore, increased their organoleptic characteristics, such as sweetness, which is that of the total sugars content (Pott *et al.,* 2019 ;2020).

The high fibre content obtained from the organic pepper fruits could be due to its higher organic minerals or inorganic minerals content (Ihemeje *et al.,* 2013 and Akinyem *et al.,* 2018), which

makes them important for little children, pregnant women and nursing mothers (Ihemeje *et al.*, 2013). Minerals enhance the important functions of maintaining acid-base balance and proper osmotic pressure in the body (Ihemeje *et al.*, 2013). Minerals are also required for normal functioning of the nerves and also muscular contraction and relaxation. Hence organic sweet pepper fruits could be a fair and cheap source of these essential minerals. (Ihemeje *et al*., 2013)

### III.2.3.8 Micronutrients of sweet pepper fruits

#### III.2.3.8.1 vitamin C

The high significant concentration of vitamin C, which was between 100.23 and 115.83 mg/100g of FM, found in fruits harvested from the plants of plots CP1-B, CP1-E, CP1-S, CP2-B, CP2-E and CP2-S both in pots and field experiments was in accordance with the findings of Taiwo, *et al.,* (2007), who reported that compost application improved vitamin C content of fruits. They are also in agreement with the work reported by (Abu-Zahra, 2014 ; Shahein *et al.*, 2015), who obtained the highest amount of vitamin C from plots amended with the sheep manure and the lowest amount from the conventional agriculture. The increase in vitamin C observed could be due to the high amount of potassium contained in cassava peels, which play a great role in plant metabolism and many important regulatory processes in the plant (El-Bassiony *et al*., 2014). Vitamin C has antioxidant properties and so have the potentials to reduce the risk of cardiovascular diseases, hypertension, chronic inflammatory diseases, diabetes and some forms of cancer (Ayodele *et al.,* 2015). Besides, sweet pepper has exceptionally high vitamin C content, the major water-soluble antioxidant in plant cells, which plays a major role in protecting cells against free radicals and oxidative damage (Wang *et al.,* 2003). Plants and most animal species synthesize their own vitamin C, but humans cannot, although they require 60-100 mg a day of this vitamin and, therefore, it must be obtained from the diet (Immaculada *et al.,* 2010). The role of Ascorbic acid (ASC) in the human diet is thought to be significant in preventing common degenerative conditionss (Immaculada *et al.,* 2010). Because the bioavailability of ASC in fruits and vegetables is equal to the availability of synthetic L-ascorbic acid, plant sources of vitamin C are considered to be more beneficial to human health because they provide other essential nutrients and phytochemicals. (Immaculada *et al*., 2010).

#### III.2.3.8.2 Minerals content

The significant high concentrations of Ca, Mg, K, Mn, Zn and Na, recorded in the sweet pepper fruits harvested from the treatments CP1-B, CP1-E, CP1-S, CP2-B, CP2-E and CP2-S both in pot and field experiments may be attributed to the quick availability of Ca, Mg, K, Mn, Zn and

Na elements and the slow release of minerals by cassava peels manure during the crop growing cycle. According to Suge *et al.*, (2011), the high concentration in menerals could be due to the fact that organic matter improved the minerals cycling and availability to the plants especially, N and P, which improved root development and subsequently vegetative growth. Similar results were reported by Abul-Soud *et al*., (2014); Elsadig *et al*., (2017) and Omar *et al.*, (2018). Moreover, that difference might be due to the presence of nitrogen and potassium in the cassava peels compost, which may have increased the amount of Ca, Mg, K, Mn, Zn and Na in the sweet pepper fruits. This is in accordence with the findings of Heidari and Mohammad, (2012) and Elsadig *et al.*, (2017), who reported that by increasing nitrogen levels, the values of microelements content increased in fruits. In addition, the highest concentration of Ca, Mg, K and Na in organic sweet pepper fruits may be due to the cassava peels manure application, which could enhance soil fertility, resulting in increasing minerals availability and their uptake by plants (Ofosu-Anim *et al.*, 2006). Furthermore, the application of cassava peels compost might provide supplemental exchangeable cations such as potassium, calcium, magnesium and ammonium, mainly due to organic manure mineralization and release of these basic cations into the soils (Al-Kahtani *et al.*, 2012).

It is interesting to note that the Na/K ratio for all the fruits obtained from organic sweet pepper plants in this study was less than 1. This suggests that they are suitable as condiments in the preparation of diets for hypertensive patients. In addition, their Ca/P ratios were above 1 therefore, could be considered good for the formation and development of bone or the calcification during skeletal formation (Aremu *et al*., 2011, Sobowale *et al.*, 2011 and Ogunlade *et al.*, 2012). Similar results were also obtained by Kemi *et al*., 2006 and Houndji *et al*., 2018. Therefore, the values of the Na/K and Ca/P ratios of this research confirmed that organic sweet pepper fruits could be useful to fight against cardiovascular diseases by promoting cardiovascular functioning and health and play an important role in the mechanism of calcification and skeletal integrity.

The high increase of the heavy metals (Cu, Zn and Mn) in fruits harvested from plants treated with CP1-B, CP1-E, CP1-S, CP2-B, CP2-E and CP2-S compored to plants grew with NPK-B, NPK-E, NPK-S might be due to the presence of those elements in the composts. But the concentration of those heavy metals was below the authorized critical limits of Value (USDA, 2016) that could affect the health. Therefore, it could be concluded that the application of cassava peels manure for the culture of sweet pepper has no risks of heavy metals toxicity.

### III.2.3.9 Content in bioactive molecules

#### III.2.3.9.1 Total polyphenol and flavonoid content

The result indicated that total polyphenols and flavonoids content were positively affected by compost application and plants spray with *O. grastissimum* aqueous extract. The highest total polyphenolic content was recorded with the highest level of compost (CP2-B). These results are in agreement with those obtained by Asami, *et al.,* (2003) , Estiarte, *et al.,* (1994). It has been reported that plants cannot simultaneously allocate resources to growth and defence and that there is a competition between proteins and phenolics in plants for the common precursors involved in their biosynthesis (Riipi, *et al*., 2002). These results led us to presume that sweet pepper plants may utilize benefits from compost fertilizer for their protein synthesis and growth development. These results are in agreement with the results of Aminifard *et al.,* (2013) on the effect of compost on antioxidant components and fruit quality of sweet pepper, who found that compost act as precursors or activators of phytohormones and growth substances and secondary compounds in plants. In the same line, these results also agree with Mitchell *et al.,* (2007), who reported that organic crop management practices increased the content of flavonoids in tomatoes. Moreover, the increasing amount of total polyphenols and flavonoids could also due to plants spray with *O. gratissimum* aqueous extract, that played the role of elicitor by inducing the defence systems of the pepper plant which in turn increased the synthesis of the secondary metabolites such as polyphenols and flavonoids (. Pott *et al.,* 2019)

Polyphenolic compounds represent the most important group of natural antioxidants (Goncalves *et al.,* 2017). One of the most common phenolic compounds are flavonoids. It has been reported that phenolic and flavonoid compounds act as antioxidants to exert antiallergic, anti-inflammatory, antidiabetic, antimicrobial, antipathogenic, antiviral, antithrombotic, and vasodilatory effects and prevent diseases such as cancer, heart problems, cataracts, eye disorders, and Alzheimer's (Zübeyir *et al*., 2017). Also, the most important features of flavonoids include their ability to protect against oxidative diseases, activate or inhibit various enzymes bind specific receptors, and protect against cardiovascular diseases by reducing the oxidation of low-density lipoproteins (Zübeyir *et al.,* 2017).

#### III.2.3.9.2 Antioxidant potential of sweet pepper fruits

##### III.2.3.9.2.1 Radical scavenging activity

The results of DPPH inhibition of extracts of fruits harvested from sweet pepper plants grown organically (CP1-B and CP2-B) were the most effective DPPH radical scavengers than the one

obtained from the plants grown conventionally (NPK-S)**.** This is in accordance respectively with the findings of Aminifard *et al*., (2013), on the effect of compost on antioxidant components and fruit quality of sweet pepper and Radames Trejo *et al*., (2018), who found that organically grown fruits and vegetables have high levels of antioxidant activity than conventionally grown products. Those results may be due to the high total polyphenol and flavonoid content that was observed in the treatments (CP1-B and CP2-B) or because plants cannot simultaneously allocate resources to growth and defence and that there is a competition between proteins and secondary metabolites in plants for the common precursors involved in their biosynthesis (Riipi, *et al.,* 2002). That might be the reason why pepper plants may utilise benefits from compost fertilizer for their protein synthesis and growth development.

Organic fertilizers (compost) act as precursors or activators of phytohormones and growth substances and secondary compounds in plants (Vernieri, *et al*., 2006, Mitchell *et al*., 2007, and Szafirowska *et al*., 2008). Another hypothesis explaining increases of antioxidant compounds in organic sweet pepper fruits was the lack of the utilization of synthetic insecticide, fungicide, and herbicide that allowed plants to devote higher resources to fight pathogen attacks, which, includes generation of antioxidant compounds (winter and Davis, 2006). In addition, it could be due to the positive influence of cassava peels compost on sweet pepper fruit quality in terms of antioxidant and defence molecules of sweet pepper. Or it might also be explained considering the nutrient released in the soil by the cassava peels compost application, which could have increased the activity of antioxidant enzymes related to the synthesis of polyphenols and flavonoids by plants as a defence mechanism to counteract the negative effects of oxidative stress (Faezah *et al*., 2013, Meloni *et al*., 2008 and Valencia *et al.,* 2018). These results may be also explained by the effect of *O. gratissimum* extract spray, which induced the synthesis of secondary metabolites such as polyphenols and flavonoids compounds in sweet pepper. Moreover, the aqueous extract of *O. gratissimum* could provide some phytonutrients for the nutrition of the pepper plants and increased the quality of fruits therefore, the greatest antioxidant capacity (Shikha *et al.,* 2014 and Trejo *et al.,* 2018).

#### III.2.3.9.2.2 Reducing Ferric Capacity (FRAP: Ferric Reducing Antioxidant Power)

For the FRAP assay, fruit extracts from plot CP2-B, exhibited the highest antioxidant power followed by CP1-B. This could be due to the richness of pepper fruits in vitamin C, flavonoids, and polyphenols content or the presence of hydroxyl groups in the polyphenolic compounds that might provide the essential component as a radical scavenger. Or the capability of those

compounds to reduce oxygen-derived free radicals by contributing a hydrogen atom or an electron to the free radical (incomplete sentence) (Wanasundara and Shahidi, 1998). It could also be due to the supplement root colonizing microorganisms of the sweet pepper via the application of compost such as Trichoderma spp, Bacillus spp, and Pseudomonas spp, which could have activated the biological pathways in plants to produce compounds such as lignins, phenolics, polyphenolics, and enzymes involved in plant defence mechanisms (Stone *et al.*, 2003). Or as stated above it might be also due either to the elicitor effect of the aqueous extracts of *O. gratissimum* on sweet pepper plants or their richness in phytochemical components such as tannins, steroids, flavonoids; etc. ( Prabhu *et al*., 2009). These results are in accordance with numerous authors that have also indicated a similar pattern in the antioxidant potential in various crops grown in soils fortified with organic wastes, signifying that compost causes variations that favour the increase of antioxidants (Martins *et al.,* 2005 and Siddiqui *et al.,* 2020). Additionally, organic fertilizers and manuring have been demonstrated to enhance the antioxidant content of plants while inorganic fertilizers are reported to cause a drop in the antioxidant contents (Dumas *et al.,* 2003 and Siddiqui *et al.,* 2020). Moreover, Abdelbasset *et al*., 2011 has also reported that the manuring effect of the amended organic matter significantly improved the antioxidant property of plants (Siddiqui *et al.,* 2020).

**III.2.3.9.2.3 Total Antioxidant Capacity (TAC)**

The highest value of TAC was obtained from fruits harvested from sweet pepper plants grown with CP1-B and CP2-B, as the results obtained from DPPH and FRAP assays. These results are in agreement with several findings that reported that organic fertilizers give the best values of TAC over the conventional fertilizers (Din *et al*., 2007) and organic fertilizers may increase the content of ascorbic acid and total phenolics in tomato. Organic fertilizers could be responsible for producing high yields of broccoli with high quality of heads (Abou El-Magd *et al.,* 2006 ; Bimova *et al.,* 2009). The above studies are cited in support of the nutritional benefit of organic fertilizers. Bímová *et al.,* (2009), had the same results, from the study on the impact of organic fertilizers on total antioxidant capacity in head cabbage.

An antioxidant can be defined as a substance that can avoid or refrain the oxidation of biological substrates They react with free radicals and neutralize them. According to a biological point of view, antioxidant compounds can protect the cellular system from the harmful effects which cause excessive oxidation. Thus, the consumption of organic sweet pepper fruits will avoid oxidative stress, which is the imbalance between concentrations of reactive oxygen species

(ROS) and antioxidants. Therefore, fight against many disease states, such as cancer, diabetes, cardiovascular disease, atherosclerosis, and neurodegenerative diseases; etc.

### III.2.3.10 Pesticide residues of sweet pepper fruits

According to the results obtained from the pesticide residues analysis in pot and field experiments, fruits harvested from the plants sprayed with K-optimal (non-systemic insecticide) or treated with, NPK-S, CP1-S and CP2-S treatments and farmer fruits contained pesticide residues of lambda-cyhalothrin above the CODEX maximum residue limit (MRL) of 0.05 mg/kg. This is in accordance with the findings of Sopkoutie, *et al.,* 2021 who found that all the samples of tomatoes collected from Foumbot were contaminated by lambda-cyhalothrin and residue concentrations above the MRL were found in all the positive samples of lambda-cyhalothrin.

This may be due to the ability of this insecticide to have a local systemic effect (penetrative insecticide) (Shalaby, 2017). Also, although lambda-cyhalothrin is well documented as a non-systemic insecticide, such local systemic effect may result from the penetration of lambda-cyhalothrin through lenticels on the surface of pepper fruits where it acts on certain biochemical systems. Alternatively, lambda-cyhalothrin being a lipophilic compound could dissolve in the cell membrane (Shalaby, 2017).

The highest concentration of lambda-cyhalothrin (Highest value) obtained from fruits harvested under field experiment and from farmers fruits compared with those collected in pot experiments may be due to the multiple spray frequencies, which were respectively in pot experiments after every two weeks and after a week of interval in field conditions.

In gener*al,* the presence of lambda-cyhalothrin in fruits might be due to the harvesting period of time after the last day of K-optimal spraying and the result of the spraying frequency as stated above that was applyed during this study, which was the same as the Cameroonian farmers. This is in line with the findings of Galani *et al.,* 2020a, who found that pesticide residues obtained in foods sampled from Yaoundé, Douala and Bafoussam could be justified by the lack of Good Agricultural Practices leading to appropriate applications of pesticides by farmers. Therefore, this result confirms the assumption that the frequency of pesticides spraying and the harvesting of fruits the following day or two days after plants spraying can affect the fruits quality in terms of pesticide residues content.

The presence of the pesticide residues could also be the result of the lowest microelements and macroelements contained in sweet pepper fruits harvested from the plants treated with K-

optimal because, several literature reviews reported that pesticide residues could interfere with biochemical and physiological processes in plants retarding the growth of the plant and decreasing the yield. Also, they might reduce the fruit quality and may even prevent its use as food by affecting its quality parameters (Shalaby, 2017). Moreover, Radwan *et al.*, (1995), (2001) , (2004) reported that pirimphos-methyl residues appeared to have significant adverse effects on the total soluble sugars and ascorbic acid content of tomato fruits and broad bean seeds. Besides, Shalaby (2017), found that lambda-cyhalothrin residues significantly decreased the levels of all tested quality parameters (total soluble sugar, glucose, acidity, total soluble solids, ascorbic acid, β-carotene, and protein) in pepper fruits, including the microelements comparing with untreated ones. These results are also in harmony with those obtained by Shalabey *et al., (*1991), Shalaby and Eisa (1992), Salem (2011) and Shalaby (2016) working with different insecticides on the same vegetables and field crops.

### III.2.3.11 Effect of cassava peel composts on some physicochemical properties of soils over ten-weeks of experiment

According to the leterature reviews, most composts have a near neutral or slightly alkaline pH with a high buffering capacity.When applied to acid soils it elevates the pH and reduces or eliminates aluminum or manganese toxicity which can occur when soil pH is below 5.5. However, in this study, the pH of the soil significantly increased over 10 weeks of experiment. This is in line with the results obtained by Iren *et al*., (2015), who observed an increase in soil pH when cassava peel compost was mixed with soil. A similar result was also obtained when Eneje and Nwosu, 2012 mixed cow dung and cassava peel compost with soil and the work (Effects of Cassava Peel Compost on Selected Properties of Soil) run by Nyorere *et al.,* (2019). In addition in 2020, Bougnom *et al.,* also found that the compost application increase the pH of the soil. This is an indication that cassava peel compost is alkaline. That significant increase could be explained by the fact that, in organic amended soils, there is a flow of protons from the soil to the organic matter sites, which will consequently increase the pH of the soil. Additionally, organic materials are rich in humic substances and have both liming value and proton consumption capacity. Furthermore, composts might increase the hydroxide content of the soil, thereby increasing the pH. According to Mkhabela and Warman (2005), the presence of hydroxyl groups and certain ions in waste composts is the main factor which contributes to the rise of the pH in the soil. (Bougnom *et al*., 2020).

On the other hand, the percentage of total N gradually increased in the soil over ten-week. This is similar to results obtained by Izonfuo *et al.,* (2013), Iren *et al*., (2015), Hafifah *et al*., (2016), and Bougnom *et al.,* (2020). The increase of nitrogen could be the result of the highest concentration of the organic N pool present in the compost. On the contrary, the concentration of the P significantly dropped with the time. This is not in agreement with the results of Izonfuo *et al.,* (2013) and Iren *et al*., (2015), who reported a significant increase in soil phosphorus due to the addition of cassava peel compost. That drop may be the presence of enough P content in the compost, which lead to a net P mineralization and adsorption of the released P (Iyamuremye *et al.,* 1996) or could be explained by the fixation of available phosphorus in these soils by protons and cations such as Ca++ and thus transforming it into a compound not assimilable by the plant (Rivaie *et al.,* 2008). The concentration of the K significantly increased with the time. This result is in agreement with the work run by Bougnom *et al.,* (2020), who also found that the application of the compost lead to the increase of of the potassium and that increase could be led to an increase in electrical conductivity in amended soils.

Moreover, previous studies have reported significant increase of soil organic carbon following compost application (Rizzo *et al*., 2015). Our reults are not in agreement with those studies because in this study, the percentage of the organic carbon significantly dropped with the time both under control and field conditions. This might be due to the lack of organic matter from the initial soils, which might have allowed the decrease of organic matter provided by the compost application through the process of mineraliwation. Therefore, instead of having the increase of soil in organic carbon we had the decrease. In addition, the values of C/N ratios significantly dropped in soil over the time. This significant decrease is similar to the studies run by Ndonkeu *et al.,* (2020). Those values of C/N ration are important for the organic matter mineralization because Hubert and Schaub (2011) argued that high carbon-nitrogen (C:N $\geq$13.70) made decomposition slow to difficult and did not allow good mineralization of organic matter.

### III.2.3.12 Effect of treatments on some physicochemical properties of soils after ten-weeks of experiment

The soils amended with CP1-B, CP1-E, CP1-S, CP2-B, CP2-E and CP2-S had the electrical conductivities significantly higher than those amended with NPK-B, NPK-E and NPK-S plots both in pot and field experiments. Our results are similar to those obtained by Bougnom *et al.,* (2020). That increase of EC could be explained by the process of organic matter mineralisation in the soil or the production of organic acids and soluble salt. However, the value of the

electrical conductivity of each sampled soil was below the value that might cause a toxical effect on plants (3,7 à 8,8 mS/cm). Likewise, the cation exchange capacity (CEC) of the same sampled soils was significantly higher than the soils amended with NPK-B, NPK-E and NPK-S treatments. This is in line with the studies run respectively by Sarwar *et al.,* 2008, bougnom *et al.,* (2020). The increases of CEC could be due to the soil organic matter which encouraged granulation and is responsible for adsorbing power of the soils up to 90 %. All the parameters of the exchangeable cations, such as potassium, calcium, magnesium, sodium and Fer significantly increased with the compost applications compared to the initial soil (control). This is in accordance with the work done by Priyo *et al.,* (2020) on the effects of compost on soil properties and yield of pineapple (*ananas comusus l. merr*.) on red acid soil, lampung, Indonesia. This means that compost was very useful for sweet pepper plants as a source of exchangeable cations. Adugna *et al.,* (2016) expressed that the mineralization of compost would release many nutrients into the soil, such as potassium, calcium and magnesium; etc, so that the nutrients would be greatly increased. Moreover, mineral nutrients of the soil also increased by the addition of green compost. (Priyo *et al*., 2020). Overall the concentrations of the metals from the different soils amended with organic fertilizers were below the concentrations that might lead to soil toxicity. The concentrations of the heavy metals such as Copper (Cu), Zin (Zn), Fer (Fe) and manganese (Mn) in all the soil amended with cassava peels compost were higher than their concentration in the initial soils. This increase could be explained either by the non chelation and the lack of precipitation of those heavy metals by organic matter present in these soils or by the slight ustilization of them by the plant. It could also be due to the lack of complexation of those metals with organic matter (Angelova *et al*., 2013).

### III.2.3.13 Effect of treatments on total mycoflora of soils after ten-weeks of experiment

The basic soil biological properties were assessed to evaluate the effect of the threatments on soil microbial communities. Previous researches have reported changes in bacterial and fungal communities after application of organic fertilizers such as composts (Baath *et al*., 1995, bougnom *et al.,* 2020 and Mangoumou *et al.,* 2020). Similar results was obtained in this study where the populations of bacteria and fungi in the soil amended with CP1-B, CP1-E, CP1-S, CP2-B, CP2-E and CP2-S were significantly higher than the populations in the soil amended with NPK-B, NPK-E and NPK-S treatments.

Organic fertilizers are reported to enhance total microbial biomass and activity in agricultural soils, with organic matter acting as a source of energy and carbon which stimulates the growth of microorganisms in soils (Lori *et al*., 2017 and Shi *et al*., 2018). The increase in bacterial and fungal biomass in the amended soils could be the result of the improved soil chemical and physical parameters, following organic matter input. Improvement of total organic carbon, nitrogen and nutrients enhance both microbial metabolism and biomass (Ros *et al.,* 2006, Shi *et al.,* 2018). The soil microbial biomass increase might be principaly due to the stimulation of the soil indigenous community rather than the transfer of microorganisms from cassava peels compost to the soil. Or it could be due to an enhancement in the growing conditionss for native microorganisms after compost amendment (bougnom *et al.,* 2020). In addition, the increase of soil microbial communities might be also due to the incorporation of easily degradable materials contained in compost which could have stimulated the indigenous microbial activit (Ros *et al*., 2006). Moreover, cassava peels compost increases availability of nutrients in soils, stimulate microbial growth and thus microbial biomass (Gracia *et al*., 2000). Furthermore, an increase in soil pH, the result of compost application, might also affects microbial biomass and microbial activity in the soils (Perucci *et al*., 2006). Also, Kasel *et al*., (2007) and Tu *et al (*2006) respectively stated that an increase in soil clay increases soil micropores hence reducing the development of microorganism predators and thus a protective effect on total microbial biomass and high soil microbial biomass often leads to high nutrient availability to crops thus improving both the microbial biomass turnover and the degradation of non microbial organic materials.

# CONCLUSION AND PERSPECTIVES

## Conclusion

Sweet pepper production is a year-round activity in the west region of Cameroon. Pests and diseases are important constraints to sweet pepper production, which lead to a great loss of yield. The lack of knowledge in diseases and pest management, as well as pesticides application respectively constitutes a major obstacle in sweet pepper production systems. Indeed, introduction of training programs for sweet pepper farmers in the identification and management of pests and safe use of pesticides is necessary. This might increase farmer knowledge of sweet pepper diseases and pests and improve management practices, especially with the high illiteracy level among farmers. However, an alternative educational program such as the combined utilization of organic fertilizers and biopesticides are also necessary for farmers in general and specifically sweet pepper and vegetable farmers to overcome vegetable diseases without having to face financial issues and destroying the environment.

The implementation of cassava peels waste as compost is a contribution to waste valorization and also represent a suitable alternative to mineral fertilizers for poor resource farmers. The electrical conductivities (1.49 to 1.92 mS/cm), which were recorded from various composts, respected the standards value (3,7 - 8,8 mS/cm) and were below the phytotoxic levels. The pH of the produced composts was nearly neutral, favorable to the cultivation of fruits and vegetables. Composts were rich in minerals and poor in heavy metals. Moreover, they showed the germination index and rate of germination of sweet pepper seeds greater than 80%, indicating the absence of phytotoxicity. The increased amounts of cassava peels positively impacted fungi and bacteria populations. Compost of cassava peels could be recommended as organic fertilizer to remediate soil fertility and base deficiency, increase the soil microbial biomass and reduce the environmental pollution.

In addition, sweet pepper cultivated with cassava peels compost and sprayed with *O.gratissimum* aqueous extract significantly increased nutrients content such as vitamin C (by 34.97 % to 36.23 % in pot and by 31.82% to 32.84% in field); sweet pepper fruits yield (by 66% to 93 % in pot and by 125% to 187% in field), the shelf life, organoleptic properties of sweet pepper fruits including nutrients and antioxidant properties such as TAC (by 13.99% to 20.05% in pot and by 13.42% to 20.63% in field) which increased with the increasing amount

of compost. Compost at 2kg/3kg and 6kg/plot and plants sprayed with 5% of *O. gratissimum* aqueous extract were the best treatments both in pots and field experiments. The spray of k-optimal (lambda-cyhalothrin) appeared to be one of the main causes that decreased the levels of all tested quality parameters in sweet pepper fruits, including microelements. Moreover, sweet pepper fruits sprayed with the same insecticide contained pesticide residues, which were above the CODEX MRLs in pot and field experiments. Therefore, the combined use of aqueous extract of *Ocimum gratissimum* leaves as biopesticide and bioinsecticide and soil amendment with cassava peels compost at 2kg/3kg and 6kg/plot could be used as alternative to conventional agrochemicals to increase the yield, the nutritional values or quality of fruits and vegetables. Furthermore, organic sweet pepper fruits are good ingredients to fight against malnutrition and metabolic diseases.

# Perspectives

Based on the results and conclusions of this study, the following perspectives are suggested for further reseach devoted to:

- Analyze the quality of fruits after the shelf life evaluation;
- Analyze the sweet pepper plants resistance enzymes;
- Isolate and identify the microorganism responsible for the wilt of sweet pepper leaves;
- Isolate and identify the beneficial microorganisms of cassava peels compost including some enzymatic activities;
- Isolate and Identify the microorganisms or enzymes responsible for the detoxification of cyanide during the composting process;
- Evaluate the effect of the combined use of the bioinput on the cultivation of other crops

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# ANNEX

## ANNEX

## Annex 1 : FICHE D'ENQUÊTE SUR LA CULTURE DU POIVRON

Cher agriculteur,
Cette fiche d'enquête a été conçue pour recueillir (dans le cadre de mes travaux de recherche) des informations sur la culture du poivron et les maladies qui affectent cette culture. Veuillez nous aider en remplissant les questions ci- dessous.

Nous vous remercions.

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### A- SECTION ADMINISTRATIVE

#### I- IDENTIFICATION

Région :……Département : ……. Arrondissement *:* ……..

Village : …….. Quartier : ……..

Noms et prénoms de l'enquêté(e) : …….. Sexe : Masculin /____/ ; Féminin /____/

Age de l'enquêté ……..ans. Niveau d'instruction de l'enquêté : Primaire/__/ ; secondaire /__/ ;

Supérieur /__/ Autre (à préciser) ..... Date de l'interview : …….

Contact:

……

,

### B- BSECTION TECHNIQUE

#### 1- SEMENCES ET PETITS MATERIELS

I-1 Quels sont les petits matériels que vous possédez ? 1- Arrosoir : 1- Oui /_/; 2- Non /_/ ; 2- Moto pompe : 1- Oui /_/; 2- Non /_/ ; 3- Râteaux : 1- Oui /_/ ; 2- Non /_/ ; 4- Pèles/houes : 1- Oui/_/; 2- Non /_/ ; 5- Machette : 1- 0ui //_/ ; 2- Non /_/ ; 6-porte tout : 1- Oui /_/ ; 2- Non /_/ ; 7- Autres : 1- Oui /_/ ; 2- Non /_/ (à préciser) .....

I-2 Quelle est la provenance des semences utilisées ? 1- Marché 1- Oui /_// ; 2- Non /_/ ; 2- Revendeur : 1- Oui /_/ ; 2- Non /_/ ; 3- Voisin : 1- Oui /_/ ; 2- Non /_/ ; 4- Gic : 1- Oui /_/ ; 2- Non /_/ ; 5- encadreurs agricoles : 1- 0ui /_/ ; 2- Non /_/ ; 6- Services du Minader : 1- Oui /_/ ; 2- Non /_/ ; 7- don 1- Oui /_/ ; 2- Non /_/ ; 8- Autres : 1- Oui/_/ ; 2- Non /_/ ;(à préciser) ..... .

I-3 Quelles sont les variétés de semences utilisées ?

……..

……..

I-4 Quels sont les prix d'achat des différentes variétés de semences ?

……..

I-5 Les semences sont-elles traitées avant leur utilisation? 1-0ui /_/ ; 2-Non /_/

Si Oui comment les traitez-vous ?

.....

.....

.....

Si non pourquoi ? ……..

**II- II-PREPARATION DU CHAMP**

II-1 Quelle est la superficie totale allouée à la culture du poivron? ……ha

II-2 Combien de campagnes pratiquez-vous ? Une campagne /__ / ; Deux campagnes /___/

II-3 Quel type de pépinière utilisez-vous ? Germoir /___/ ; Planche /__/; Billon /_/; Autre /___/.

II-4 Où est localisée votre pépinière ? 1- A côté du champ /__/; 2- loin du champ /__/. (Varie en fonction de la source d'eau)

II-5 Traitez-vous les semences avant de les mettre en pépinière ? Oui /_); Non /_) ; si oui indiquez la méthode de traitement .....

II-6 Quelle est la fréquence de traitement des semences en pépinière ? Une fois /jour /___/; Une fois/semaine /__/ ; Deux fois/mois /___/; Trois fois/mois /.../ Autre /___/ (à préciser) .....

II-7 Quels sont les types de produits utilisés pour le traitement en pépinière ?

1-insecticides : Oui /___/ ; Non /___/ ; si oui donner le nom du produit ..... .....

2- fongicides : *Oui /___/ ;* Non /___/ ; si oui donner le nom du produit ..... .

3-Autres: *Oui /___/ ;* Non /___/ ; (à préciser) .....

II-8 Combien de temps dur la pépinière ? une semaine /_/; deux semaines /_/ ; trois semaines /_/; un mois /...../ un mois et demi /___/, Autre /_) (à préciser) ..... ……..

II-9 Y-a-t-il souvent les attaques/maladies des plantules en pépinière ? Oui /___/; Non /___/ ;

Si oui quelle sont les principales attaques/maladies? .....

II-10 Utilisez-vous les engrais en pépinière ? 1- Oui /___/; 2- Non /___/ ; si oui lesquels ? .....

II-11 Faites-vous les rotations des parcelles dans la culture de poivron? 1- Oui/__/; 2- Non /__/ ; Si oui quelle est la durée de la jachère ..... .

II-12 Les champs où sont repiqués les plants sont-ils : 1- Billon/___/; 2- Planche /___/ ; 3- Autre /___/

II-13 Pratiquez-vous d'autres cultures dans les champs de poivron? 1- Oui /__/ ; 2-Non/___/; si oui lister les cultures en association avec la culture du poivron.

……

11-14 Où achetez-vous les semences de poivron? . .....

11-15 En quelle période de l'année cultivez-vous le poivron ? (cocher)

Janvier /_/; Février /_/; Mars /___/ Avril ; /_/Mai /_/; Juin /_/; Juillet [ ] ; Aout [ ] ; Septembre [ ] ; Octobre [ ] Novembre [ ] ; Décembre /__/; [ ] durant toute l'année

**III-III- Plants de Poivron**

III-1 Comment réalisez-vous le repiquage des plants ?

……

III-2 Utilisez-vous les engrais dans les champs de poivron ? 1- Oui /_/ 2- Non /_/

Si oui à quelle fréquence ? ……

Et quel est le dosage ? ……..

Si non Pourquoi ? ……

III-3 Quelles sont les principales maladies ou symptômes observées pour la culture du poivron ?.

. ……

……..

……..

III- 4 Quels sont les pesticides utilisés pour le traitement du poivron? (Cocher en précisant le(s) nom(s) du ou des pesticide( s))

a) Insecticides / /

……

……

b) Fongicides /_/

……

……

c) Autres [ ]

……

Quel est the dosage des pesticides?.....

……

……

III-5 A quel moment les plantes sont-elles exposées aux maladies ?

1- Une semaine/-/; 2- Deux semaines /-/ ; 3- Quatre semaines /-/ ; 4- Six semaines /-/ ; 5-Autre /-/ ;

III-6 Quelles sont les parties concernées lors des attaques par les maladies et ravageurs?

1- Feuilles [ ], tiges [ ] ; fruits [ ] ; /_/toute la plante ;

III- 7 A quel moment sont récoltés les fruits après la dernière pulvérisation?

Un jour : /_/ ; 2- Une semaine //_/ ; 3- Deux semaines /_/ ; 4- Autres /_/

lll-8 Vous cultivez le poivron il y'a de cela combien d'années?.....

III-9 Recevez-vous de l'aide pour le diagnostic des maladies du poivron? [ ] Oui [ ] Non (cocher)

Si oui quelles sont les raisons:

[ ] je ne connais pas les symptômes

[ ] je ne peux pas reconnaitre les maladies

[ ] je ne connais pas les traitements

Source d'aide préférée:

[ ] agriculteurs locaux

[ ] technicien d'agriculture

[ ] les vendeurs d'engrais et pesticides

[ ] Autres……

la sources d'aide vous apportent-elles une grande aide [ ] Oui [ ] Non (cocher)

Si non quelle est la raison :

[ ] sont toujours indisponibles

[ ] Couteux

[ ] Pas informatives

[ ] Inefficaces

Connaissez-vous les causes des maladies du poivron? [ ] Oui; [ ] Non

Si oui quelles sont les causes?.....

……

…….

**VI- ENTRETIEN ET IRRIGATION DU CHAMP**

VI-1 Comment entretenez-vous vos champs de poivron? 1- Binage /_// ; 2- Sarclage /_/ ; 3- désherbage /_// ; 4- Autre /_/ ;(à préciser) ..... .

VI-2 Comment arrosez-vous vos champs de poivron? 1- Par irrigation avec la moto pompe /_// ; 2- Avec les arrosoirs /_/ ; 3-Autre /_/ ;(àpréciser) ..... .

VI-3 Quelle est la provenance d'eau utilisée pour l'arrosage de vos champs ? 1- Marécage /_/ ; 2- source d'eau /_/ ;

VI-3-1 Gravitation/eau sortant des montagnes /_/ ; 4- Autre /_/

VI-4 Quelles sont les parties concernées lors de la pulvérisation ?

VI-4-1- Feuilles [ ], tiges [ ] ; fruits [ ] ; /_/toute la plante ; autres.....

**V-RECOLTE**

V-1 Quelle quantité de poivron récoltez-vous par campagne ? ..... ..... tonnes

V-2 Quel est le taux de perte à la récolte ? 1- 5% l_I ;2- 10% /_/ ;. 3-15% /_/ ; 4- 20% Il_/ ; 5- Autre /_/ ; V-3 A quoi sont dues ces pertes ? 1- Maladies /_/ ; 2- intempéries /_/; 3- Autre /_/

V-4 Combien de récoltes sont effectuées lors d'une campagne ? 1- Une /_/ ; 2- deux /_/ ; 3- Plus /_/

V-5 Quel est le mode de faire valoir des terres utilisées pour la culture de poivron? 1- Propriétaire /_/; 2- locataire/_/ ;3-Autre /_/

V-6 Comment récoltez-vous les fruits de poivron? On coupe le poivron avec la petite tige qui lie le fruit à la plante

V-7 Utilisez-vous les produits chimiques pour conserver vos fruits de poivron? [ ] Oui /_/Non (cocher) Si oui lesquels?

V-8 En combien de jours, de semaines ou de mois ces fruits peuvent être conservés? (cocher)

01 jour [ ]; 02 jours; [ ] 03 jours [ ] 04 jours [ ] 05 jours [ ] 06 jours [ ] 07 jours [ ] 01 semaine /_j; 02 semaines [ ] ; 03 semaines [ ] ; 04 semaines [ ]; 01 mois ; [] ; 02 mois [ ] ; 03 mois [ ] ; 04 mois [ ]

**Annex 2: The production of sweet pepper seedlings**

**Sweet pepper Seeds**

**Nursery/ beds/cow dung powders (250g/m2)**

45 days

**Seedlings**

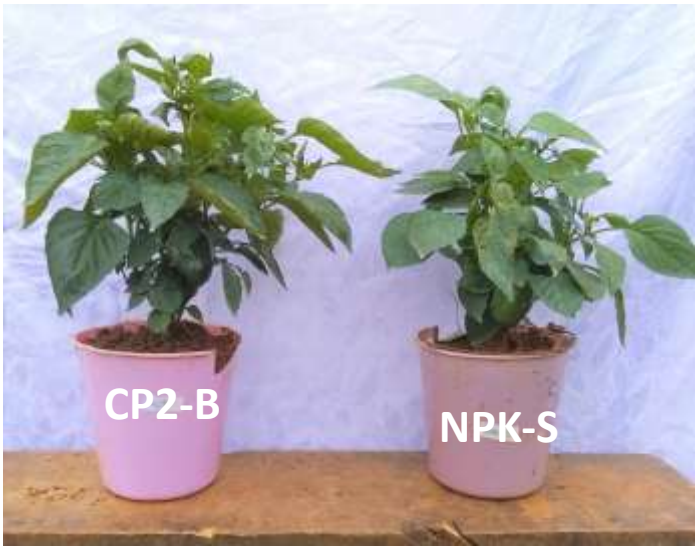
**<u>Annex 3</u>: transplantation of weet pepper seedlings in pot and field experiments**

**Seedlings**

**Pot experiment**

**<u>Annex 4</u>: Figures taken from some sections of the pot and field experiments**

Field expriment




Pot expriment


**Sweet pepper cultivated with CP2-B**


**Sweet pepper cultivated with NPK-S**

**Annex 5: A mixture of Sweet pepper fruits harvested from the plots CP1-B, CP1-E, CP1-S, CP2-B, CP2-E and CP2-S**

**Annex 6: Organoleptic analysis3**

1. How would you rate the overall **APPEARENCE/COLOUR** of this product?

| **Sample Code*** | **CP1-B** | **CP1-E** | **CP1-S** | **CP2-B** | **CP2-E** | **CP2-S** | **NPK-B** | **NPK-E** | **NPK-S** |
|---|---|---|---|---|---|---|---|---|---|
| Grade | | | | | | | | | |
| **SampleCode**** | **CP1-B** | **CP1-E** | **CP1-S** | **CP2-B** | **CP2-E** | **CP2-S** | **NPK-B** | **NPK-E** | **NPK-S** |
| Grade | | | | | | | | | |

2. How would you rate the overall **SHAPE** of this product?

| **Sample Code*** | **CP1-B** | **CP1-E** | **CP1-S** | **CP2-B** | **CP2-E** | **CP2-S** | **NPK-B** | **NPK-E** | **NPK-S** |
|---|---|---|---|---|---|---|---|---|---|
| Grade | | | | | | | | | |
| **Sample Code**** | **CP1-B** | **CP1-E** | **CP1-S** | **CP2-B** | **CP2-E** | **CP2-S** | **NPK-B** | **NPK-E** | **NPK-S** |
| Grade | | | | | | | | | |

3. How would you rate the overall **TASTE** of this product?

| **Sample Code*** | **CP1-B** | **CP1-E** | **CP1-S** | **CP2-B** | **CP2-E** | **CP2-S** | **NPK-B** | **NPK-E** | **NPK-S** |
|---|---|---|---|---|---|---|---|---|---|
| Grade | | | | | | | | | |
| **Sample Code**** | **CP1-B** | **CP1-E** | **CP1-S** | **CP2-B** | **CP2-E** | **CP2-S** | **NPK-B** | **NPK-E** | **NPK-S** |
| Grade | | | | | | | | | |

4. How would you rate the overall **ODOR/AROMA** of this product?

| **Sample Code*** | **CP1-B** | **CP1-E** | **CP1-S** | **CP2-B** | **CP2-E** | **CP2-S** | **NPK-B** | **NPK-E** | **NPK-S** |
|---|---|---|---|---|---|---|---|---|---|
| Grade | | | | | | | | | |
| **Sample Code**** | **CP1-B** | **CP1-E** | **CP1-S** | **CP2-B** | **CP2-E** | **CP2-S** | **NPK-B** | **NPK-E** | **NPK-S** |
| Grade | | | | | | | | | |

5. How would you rate the overall **SWEETNESS** of this product?

| **Sample Code*** | **CP1-B** | **CP1-E** | **CP1-S** | **CP2-B** | **CP2-E** | **CP2-S** | **NPK-B** | **NPK-E** | **NPK-S** |
|---|---|---|---|---|---|---|---|---|---|
| Grade | | | | | | | | | |
| **Sample Code**** | **CP1-B** | **CP1-E** | **CP1-S** | **CP2-B** | **CP2-E** | **CP2-S** | **NPK-B** | **NPK-E** | **NPK-S** |
| Grade | | | | | | | | | |

*Fruits harvested from the pot experiment and **Fruits harvested from the field experiment

Where:

CP1-B and CP2-B: fruits harvested from soil amended with compost and sprayed with *Ocimum Grastissimum*.

CP1-E and CP2-E: fruits harvested from soil amended with compost and sprayed with water.

CP1-S and CP2-S: fruits harvested from soil amended with compost and sprayed with Mancozeb/K-optimal.

NPK-B: fruits harvested from the soil amended with NPK (20.10.10) and sprayed with *Ocimum Grastissimum*.

NPK-E: fruits harvested from soil amended with NPK (20.10.10) and sprayed with water.

NPK-S: fruits harvested from soil amended with NPK (20.10.10) and sprayed with Mancozeb/K-optimal.

## Annex 7: Evaluation of the mineralogical composition

### Preparation of standards

### Stock solutions

**Calcium, magnesium, potassium, sodium**: A solution of 10,000 ppm K was prepared by dissolving 1.907 g of oven-dried potassium chloride. In a 100 ml of a volumetric flask, was introduced respectively 5 ml of K 1000 ppm, 25 ml of Ca 1000 ppm, 5 ml of Mg 1000 ppm and 5 ml of Na 10,000 ppm, then the volume was completed to the gauge line with the chloride solution strontium.

**Copper, iron, manganese and zinc**: In a 100 ml volumetric flask, were respectively added: 1ml of Cu 1000 ppm, 8 ml of Fe 1000 ppm, 8 ml of Mn 1000 ppm and 2 ml of Zn 1000 ppm and the volume has been completed to the gauge line with the aqua regia solution.

**Working solution**

**Calcium, magnesium, potassium, sodium**: In 5 tubes of 25 ml numbered from 1 to 5 were respectively introduced: 0.5 ml of aqua regia solution and 19.5 ml of strontium chloride solution and the whole was homogenized. From those tubes, 0; 0.25; 0.50; 0.75 and 1 ml of solution have been removed respectively. Then, they were replaced by the same quantities of the stock solution and the mixtures were vigorously stirred.

**Copper, iron, manganese and zinc:** in 5 tubes of 50 ml numbered 1 to 5 have been respectively added: 10 ml of deionized water and 30 ml of aqua regia solution and the whole was stirred. From those tubes, were taken respectively 0; 0.5; 1; 1.5 and 2 ml of solution and were replaced by the same quantities of the stock solution before being homogenized.

The concentrations of the various ranges of standards which have been prepared are presented in Tables 30 for the macro-minerals and 31 for the trace elements.

**Table 30**: The concentration of the macro-mineral standard range

| | | **Concentration (ppm)** | | | | |
|---|---|---|---|---|---|---|
| **λ (nm)** | **Tube $N^0$** | **1** | **2** | **3** | **4** | **5** |
| **422,7** | **Ca** | 0,00 | 3,10 | 6,30 | 9,40 | 12,50 |
| **285,2** | **Mg** | 0,00 | 0,60 | 1,30 | 1,90 | 2,50 |
| **766,5** | **K** | 0,00 | 6,30 | 12,50 | 18,80 | 25,00 |
| **589** | **Na** | 0,00 | 6,25 | 12,50 | 18,75 | 25,00 |

**Table 31:** Concentration of the range of trace elements standards

| | | Concentration (ppm) | | | | |
|---|---|---|---|---|---|---|
| **λ (nm)** | **Tube $N^0$** | **1** | **2** | **3** | **4** | **5** |
| **324,7** | **Cu** | 0,00 | 0,13 | 0,25 | 0,38 | 0,5 |
| **248,3** | **Fe** | 0,00 | 1,00 | 2,00 | 3,00 | 4,00 |
| **213,9** | **Zn** | 0,00 | 0,25 | 0,50 | 0,75 | 1,00 |
| **279,5** | **Mn** | 0,00 | 1,00 | 2,00 | 3,00 | 4,00 |

**Phosphorus content**

**Preparation of the standard**

The standard phosphorus solution (1000 ppm) that has been used for the calibration was prepared by dissolving 4.393 g of $KH_2PO_4$ in 1l of deionized water.

Then, via a dilutor was introduced into 5 propylene tubes of 50 ml numbered 1, 2, 3, 4 and 5 respectively 0.00; 1.25; 2.50; 3.75 and 5.00 ml of the previous solution of $KH_2PO_4$. The volume was made up to 50 ml with the aqua regia solution. The table 32 below shows the concentrations of the solutions which were prepared.

**Table 32:** Concentration of the phosphorus standard range

| | | Concentration en ppm | | | | |
|---|---|---|---|---|---|---|
| λ (nm) | Tube $N^0$ | 1 | 2 | 3 | 4 | 5 |
| 860 | P | 0 | 25 | 50 | 75 | 100 |

**Annex 8:** The below formula and equation were used to calculate the concetration of vitamin c in mg Ascorbic acid/100 g.)

**Formula for $M_{iodine}$:**

$$M_{Iodine} = mass_{ascorbic\,acid} \times \frac{1 mole_{ascorbic\,acid}}{176.12 g_{ascorbic\,acid}} \times \frac{1000 \, mL/L}{Volume_{Iodine\,solution,\,mL}}$$

**Formula for Concentration of Ascorbic Acid**

$$mg_{ascorbic\ acid} = M_{iodine\ solution} \times mL_{iodine\ solution} \times 176.12\,{}^{g}/_{mole}$$

**Equation**

**Concentration**$_{AscorbicAcid}$ **in fruit used** = (**Average Conc**$_{AscorbicAcid}$ / **AverageVolume**$_{fruit\ extract}$) / (**1ml** $_{fuit\ extract}$ /**1 g** $_{fruit\ extract}$) **X100**

**<u>Annex 8</u>: Instrument used for GC method:**

Gas chromatograph : Agilent GC 7890A ; Detector : Mass Spectrophotometer (Agilent 5975 C TAD VL MSD)

Working conditionss of the Chromatograph :

Ionisation mode : Electronic impact(EI)

Colonne : HP-MS ( 30m x 0.250mm x 0.25µm )

Column flow rate : 1.2 ml/min

Injection volume : 1µl

Injection system : Splittless mode

Carrier gas : Helium

# Annex 9: Published articles

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SURVEY ARTICLE

# The Cultivation of Sweet Pepper (*Capsicum Annuum*) in Foumbot Agricultural Area, West Region, Cameroon

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## ABSTRACT

This study aimed to get information on the cultivation of sweet pepper from the North West Region of Cameroon (Foumbot). Data for the study were obtained from 92 farmers with the aid of well-structured questionnaires. Results obtained showed that among the sweet pepper farmers, males represented 80% of the sampled population and women 12%, all of them aged between 18 to 48 years old. Their level of education varies from primary school to University with the majority found between primary school (48%) and secondary school (30%). 41% of the sampled cultivators have the greatest level of experience in between 10 to 30 years and 52% with the lowest level of experience varying from 1 to 10 years. The sweetest pepper varieties cultivated was Yolo wonder and Simba. 89 % of respondents had a sweet pepper field with a surface area between 0.5 and 1 hectare. According to farmers, the nursery is usually attacked by fungi after one week of growth, which always cause stems rot. Fungicides (Mancostar 80WP) and insecticides (Mocap EC, Timik, Plantineb 80WP, Jumper and Ascot) are the most chemical products used to treat stems rot. Cypermethrin and Mancozeb represent respectively 63% and 85% of active ingredients used by the sampled growers to fight against sweet pepper diseases. 46 % of the sampled farmers said that they prefer spray pesticides in all stages while 44% of sweet pepper farmers did not take note of the number of times, they applied chemicals pesticides on their crops. NPK: 20.10.10 is the most chemical fertilizer used to grow sweet pepper. The major diseases and pests encountered in that region are (1) diseases: Mildew, cercospora leaf spot, phytophthora blight, fusarium wilt, anthracnose, ripe rot, tobacco mosaic virus, cucumber mosaic virus, and gal formations; (2) pests: flee beetles, cutworms, aphids, vegetable weevil, caterpillars, grasshoppers, pepper maggots and leaf miners.

**Keywords:** sweet pepper farming, pest and diseases management, chemical usage, Foumbot

## 1 Introduction

In Cameroon in general and in the Foumbot agricultural area in particular, synthetic pesticides have been widely overused by farmers. (Galani *et al.*, 2020, Sonchieu *et al.*, 2017; Tandi *et al.*, 2014,) In this area, vegetables are the most produced foods alongside maize and beans. They are produced throughout the year and have grammatically contributed to food security in the zone (Houjayfa *et al.*, 2020, Mfopou*et al.*, 2017) The main vegetable crops cultivated are green beans (Phaseolus vulgaris L.), sweet pepper (Capsicum annuum L.), watermelon (Citrillus lanatus L.), leeks (Allium porrum L.), tomato, lettuce (Lactucasativa L.), amaranth (Amaranthus cruentus L.), huckleberry (Solanum scabrum Mill.), carrot (Daucus carota L.), pepper (Capsicum frutenscens L.), cabbage (Brassica oleraceae var. capitata L.) and traditional vegetables. (Joseph *et al.*, 2020, Sonchieu *et al.*, 2018 ; Tabe-Ojong *et al.*, 2017). Vegetables are a source of micronutrients and important source of proteins, minerals, vitamins, and amino acids (Lal *et al.*, 2020, Tata *et al.*, 2016Asongwe *et al.*, 2014 ;). In Cameroon, commonly grown exotic vegetables include tomato (Lycopersicon esculentum), onion (Allium cepa), cabbage (Brassica oleracea) and sweet pepper (Capsicum

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RESEARCH ARTICLE

# The Potential of Cassava (*Manihot esculenta Crantz*) Peels as an Organic Fertilizer

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## ABSTRACT

Cassava peels are in large quantity and practically of no economic value in many developing nations such as Cameroon, where cassava is widely consumed and processed far beyond other crops. Cassava peels might be used in those countries to face declining soil fertility and soil erosion. This study aimed to evaluate the composting of cassava peels without any additional material and the effect of the increasing quantity of cassava peels in the bin during the process of composting and to assess some physico-chemical qualities, biological properties and the phytotoxicity of the produced composts. After three months of composting the produced composts (C1; C2; C3 and C4) had a dark brown color, relatively dry, uniform structure and its texture were similar to the soil's texture. Their electrical conductivity was in between 1499 and 1924 $\mu S.cm^{-1}$.Their pH (6.50-6.73), was slightly acid, great for the cultivation of sweet pepper. They were rich in minerals (Mg; Ca; K+; and Na+) and poor in heavy metals such as (Cu, Zn and Mn). The composts C/N ratios were between 13.15 to 13.42. The produced composts showed a germination index and the rate of germintion greater than 80% at all concentrations, indicating the absence of phytotoxicity. The increased amounts of cassava peels did not undermine the process of composting and positively impact fungi and bacteria populations. Indeed, cassava peels are good subtracts that can be used to produce stable organic fertilizers, with higher liming potential, nutrient content, and less hazardous material which could be used in farms to remediate declining soil fertility and to promote sustainable agriculture.

**Keywords :** Cassava peels composting, phytotoxicity, sustainable agriculture.

## 1 Introduction

Cassava (*Manihot esculenta Crantz, Euphorbiaceae*) is the sixth most important food crop globally, in terms of annual production, and is a staple food for approximately 800 million people [1]. This perennial root crop is grown in the tropics, including sub-Saharan Africa, Asia, the Pacific Islands, and Central and South America [1]. Cassava is cultivated in more than 100 countries worldwide [2]. It holds the position of the strategic crop in many tropical countries, [2] such as Cameroon. In Cameroon, it is a leading crop in terms of annual yield both for cash and food crop categories. It is widely consumed and processed far beyond other crops such as maize and rice [2]. Cassava is cultivated for its starchy roots and is a staple food material in many developing countries, including Cameroon, where it is eaten as garri, fufu, or other products. According to the Central Bureau of Statistics in 2004-2008, the production of cassava peel tend to increase annually which means the production of cassava peel also increasing [3]. Cassava peel is the peeling of food product from cassava. The Chemical composition of cassava peel is identic with cassava which contains most of the polysaccharide and some of mineral and water.

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# Effect of aqueous extract of clove basil (*Ocimum gratissimum* L.) and soil amendment with cassava peels compost on nutrients, pesticide residues, yield and antioxidant properties of sweet pepper (*Capsicum annuum* L.)

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*Keywords:*
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ABSTRACT

Natural agricultural inputs in sweet pepper cultivation can be beneficial for nutritional quality, and environmental and food safety. This research assessed the effect of the combined use of clove basil (*Ocimum gratissimum*) aqueous extract and cassava peel compost on the nutrients, pesticide residues, yield and antioxidant properties of sweet pepper fruits. The experiment was a split plot design of 04 blocks with 03 plots each and 03 repetitions, conducted in pots and in the field. The soil was amended with compost at 1kg/4kg and 2kg/3kg in pots, with 3kg/plot and 6kg/plot on field experiment, and 26.3 g of NPK (20.10.10) per plant was used as an inorganic amendment both in pots and field. Plants in both experiments were sprayed with clove basil extract, insecticide lambda-cyhalothrin or water. Sweet pepper fruits cultivated with composts and sprayed with clove basil extract exhibited the highest values of nutritional parameters, antioxidant properties and increased the yield by 93% in pots and 187% on field, as compared with synthetic fertilizer treatments. Organic fruits were free from pesticide residues and had the best values of Na/K and Ca/P ratios which are good indicators of their nutritional values. Sweet pepper plants sprayed with lambda-cyhalothrin or from farmers contained lambda-cyhalothrin at concentration of 0.0199 mg/kg. These results show that organic treatments improved the fruit nutrients, health-promoting properties and safety, and could be used to enhance the nutritional quality of sweet pepper while providing an efficient way of sustainable agriculture.

## 1. Introduction

Malnutrition is the consequence of disease poverty, hunger, war, and natural catastrophe and more than 1 billion people suffered from malnutrition (Cederholm et al., 2019). In Africa, the estimated number of undernourished people increased to 821 million (10.9%) in 2017, up from 784 million (10.6%) in 2015. In 2017 worldwide, malnutrition affected 151 million children (22.2%) and 51 million children under five (7.5%) suffered from wasting (FAO et al., 2020). Micronutrient deficiencies have been identified as major public health problems affecting a large part of the world's population with pregnant women and children under 5 years at the highest risk (Manjeru et al., 2019). On the other hand, many other illnesses are known to be associated with malnutrition, such as stroke, Parkinson's disease and diseases of the mouth and throat (Wells et al., 2003 and Suominen et al., 2005). One of the main causes of malnutrition is the deficiencies in the minerals calcium, iodine, iron, selenium, zinc, and vitamins such as folate and vitamin A (WHO and UNICEF, 2017 and Galani et al., 2020a). Micronutrients play important roles in human health and can retard growth and cognitive development, impair immunological functioning and increase the risk of non-communicable diseases including skeletal, cardiovascular and metabolic disorders (WHO/FAO 2003, Fairweather-Tait et al., 2011; Galani et al., 2020a). Moreover, It was reported that about half of all anemia is attributable to iron deficiency depending on the geographic and disease environment (Darnton-Hill & Mkparu 2015). One of the principal means to reduce malnutrition could be the increase in food intake and the cultivation of fruits and vegetables that are rich in micro- and macronutrients like tomato, okra, carrot, eggplant, chilli and peppers (Dhaliwal et al., 2017), including sweet pepper.

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