

CONTENTS

<i>Content</i>	<i>Page No.</i>
a) Abstract	i – v
b) Declaration by the Candidate	vi
c) Certificate of the Supervisor	vii
d) Acknowledgement	viii - x
e) Table of contents	xi - xvi
f) List of tables	xvii
g) List of figures	xviii – xxiii
h) List of abbreviations	xxiv – xxvi
i) List of symbols	xxvii
 CHAPTER 1: Introduction	 [1-32]
1.1 Overview	2-6
1.2 General introduction to milk adulteration and contamination	6-9
1.3 Metal nanoparticles (NPs) as plasmonic nanomaterials (NMs)	9-14
1.3.1 Properties	9
1.3.1.1 Optical properties	9
1.3.1.2 Morphological properties	10
1.3.1.3 Structural properties	11
1.3.2 Synthesis of plasmonic NMs	11
1.4 Literature review	14-17
1.5 Objectives of the present study	17-18
1.6 Outline of the thesis	18-20
References	20-32
 CHAPTER 2: Colorimetric sensing of milk adulterants	 [33-106]
2.1 Introduction	34-39
2.2 Materials and methods	39-40
2.3 Instrumentation	40

CHAPTER 2A: Colorimetric sensing of milk adulterants without substrate	[41-70]
2.A.1 Colorimetric sensing of melamine by <i>Camellia sinensis</i> functionalised AgNPs	41-48
2.A.1.1 Synthesis of <i>Camellia sinensis</i> leaves functionalised AgNPs and pretreatment of milk	41
2.A.1.2 Characterisation of <i>Camellia sinensis</i> leaves extract functionalised AgNPs	42
2.A.1.3 Colorimetric sensing	44
2.A.1.3.1 Mechanism	45
2.A.1.3.2 Selectivity study	46
2.A.1.3.3 Sensor performance metrics	47
2.A.2 Colorimetric sensing of hydrogen peroxide by <i>Bombax ceiba</i> leaves functionalised AgNPs	49-55
2.A.2.1 Synthesis of <i>Bombax ceiba</i> leaves functionalised AgNPs	50
2.A.2.2 Characterisation of <i>Bombax ceiba</i> leaves functionalised AgNPs	50
2.A.2.3 Colorimetric sensing	52
2.A.2.3.1 Mechanism	53
2.A.2.3.2 Selectivity study	54
2.A.2.3.3 Sensor performance metrics	55
2.A.3 Colorimetric sensing of formalin by l-cysteine functionalised AgNPs	56-62
2.A.3.1 Synthesis of l-cysteine functionalised AgNPs	56
2.A.3.2. Characterisation of l-cysteine functionalised AgNPs	57
2.A.3.3 Colorimetric sensing	59
2.A.3.3.1 Mechanism	59
2.A.3.3.2 Selectivity study	59
2.A.3.3.3 Sensor performance metrics	61
2.A.4 Colorimetric sensing of salicylic acid by <i>Citrullus lanatus</i> rind functionalised AgNPs	62-68
2.A.4.1 Synthesis of <i>Citrullus lanatus</i> rind functionalised AgNPs	63
2.A.4.2 Characterisation of <i>Citrullus lanatus</i> rind functionalised	64

AgNPs	
2.A.4.3 Colorimetric sensing	66
2.A.4.3.1 Mechanism	66
2.A.4.3.2 Selectivity study	67
2.A.4.3.3 Sensor performance metrics	68
2.A.5. Conclusion	69
 CHAPTER 2B: Colorimetric sensing of milk adulterants and contaminants with substrate	[71-96]
2.B.1 Synthesis, functionalisation of AgNPs and pretreatment of milk	71
2.B.1.1 Synthesis of maleic acid functionalised AgNPs	71
2.B.1.2 Synthesis of l-cysteine functionalised AgNPs	72
2.B.1.3 Synthesis of <i>Camellia sinensis</i> encapsulated AgNPs	72
2.B.1.4 Synthesis of poly-vinyl alcohol (PVA) functionalised banana root bulb (BRB) reduced AgNPs	73
2.B.1.5 Synthesis of citric acid functionalised AgNPs	73
2.B.1.6 Synthesis of salicylic acid functionalized AgNPs	74
2.B.1.7 Synthesis of l-glutamine functionalised AgNPs	74
2.B.1.8 Pretreatment of milk	75
2.B.2 Characterisation of the functionalised AgNPs	75
2.B.2.1 Characterisation of maleic acid functionalised AgNPs	75
2.B.2.2 Characterisation of l-Cysteine functionalised AgNPs	76
2.B.2.3 Characterisation of <i>Camellia sinensis</i> encapsulated AgNPs	76
2.B.2.4 Characterisation of poly-vinyl alcohol (PVA) functionalised banana root bulb (BRB) reduced AgNPs	76
2.B.2.5 Characterisation of citric acid functionalised AgNPs	76
2.B.2.6 Characterisation of salicylic acid functionalized AgNPs	78
2.B.2.7 Characterisation of l-glutamine functionalised AgNPs	78
2.B.3 Fabrication of paper-based platform	80
2.B.4 Colorimetric sensing in paper-based platform	82
2.B.4.1 Melamine sensing	82
2.B.4.1.1 Mechanism	83

2.B.4.1.2 Sensor performance metrics	83
2.B.4.2 Formalin sensing	84
2.B.4.2.1 Mechanism	84
2.B.4.2.2 Sensor performance metrics	85
2.B.4.3 Hydrogen peroxide sensing	85
2.B.4.3.1 Mechanism	86
2.B.4.3.2 Sensor performance metrics	86
2.B.4.4 Mercury ion sensing	86
2.B.4.4.1 Mechanism	87
2.B.4.4.2 Sensor performance metrics	88
2.B.4.5 Arsenic ion sensing	89
2.B.4.5.1 Mechanism	90
2.B.4.5.2 Sensor performance metrics	90
2.B.4.6 Cadmium ion sensing	91
2.B.4.6.1 Mechanism	91
2.B.4.6.2 Sensor performance metrics	91
2.B.4.7 Lead ion sensing	92
2.B.4.7.1 Mechanism	93
2.B.4.7.2 Sensor performance metrics	93
2.B.5 Simultaneous sensing of multiple adulterants and contaminants in the paper-based platform	94
2.B.6 Conclusion	96
References	96-106
 CHAPTER 3: Localised surface plasmon resonance (LSPR) based sensing via plasmonic nanofilms	 [107-132]
3.1 Introduction	108
3.2 Materials and methods	110
3.3 Instrumentation	110
3.4 LSPR based sensing of melamine by maleic acid functionalised AgNPs	[111-117]
3.4.1 Synthesis of maleic acid functionalised AgNPs and pretreatment of milk	112

3.4.2	Characterisation of maleic acid functionalised AgNPs	112
3.4.3	LSPR based plasmonic sensing	113
3.4.3.1	Fabrication of the sensor	113
3.4.3.2	Mechanism	114
3.4.3.3	Selectivity study	115
3.4.3.4	Sensor performance metrics	116
3.5	LSPR based sensing of hydrogen peroxide by PVA functionalised <i>Ocimum tenuiflorum</i> reduced AgNPs	[118-126]
3.5.1	Synthesis of PVA functionalised AgNPs and pretreatment of milk	119
3.5.2	Characterisation of PVA functionalised AgNPs	120
3.5.3	LSPR based plasmonic sensing	121
3.5.3.1	Fabrication of the sensor	121
3.5.3.2	Mechanism	122
3.5.3.3	Selectivity study	123
3.5.3.4	Sensor performance metrics	124
3.6.	Conclusion	126
	References	126-132
CHAPTER 4: Plasmonic nanomaterial based electrochemical sensing		[133-179]
4.1	Introduction	134
4.2	Materials and methods	135
4.3	Instrumentation	136
4.4	Electrochemical sensing of urea	[136-147]
4.4.1	Synthesis of APTES coated <i>Camellia sinensis</i> reduced AuNPs and pretreatment of milk	139
4.4.2	Characterisation of APTES coated <i>Camellia sinensis</i> reduced AuNPs	139
4.4.3	Electrochemical sensing	140
4.4.3.1	Fabrication of the sensor	140
4.4.3.2	Preliminary investigation of the working electrode	141
4.4.3.3	Mechanism	142
4.4.3.4	Sensor performance metrics	144

4.5 Electrochemical sensing of melamine	[148-159]
4.5.1 Synthesis of polyethylene glycol (PEG) coated maleic acid functionalised AgNPs and pretreatment of milk	150
4.5.2 Characterisation of the PEG coated maleic acid functionalised AgNPs	151
4.5.3 Electrochemical sensing	153
4.5.3.1 Fabrication of the sensor	153
4.5.3.2 Preliminary investigation of the working electrode	153
4.5.3.3 Mechanism	153
4.5.3.4 Sensor performance metrics	155
4.6 Electrochemical sensing of hydrogen peroxide	[160-170]
4.6.1 Synthesis of polyvinyl pyrrolidone (PVP) functionalised AgNPs and pretreatment of milk	161
4.6.2 Characterisation of polyvinyl pyrrolidone (PVP) functionalised AgNPs	162
4.6.3 Electrochemical sensing	164
4.6.3.1 Fabrication of the sensor	164
4.6.3.2 Preliminary investigation of the working electrode	164
4.6.3.3 Mechanism	164
4.6.3.4 Sensor performance metrics	166
4.7 Conclusion	170
References	171-179
 CHAPTER 5: Discussion and comparative analysis	 [180-198]
5.1 Comparative analysis of colorimetric sensing architectures	181-188
5.2 Comparative analysis of LSPR-based sensing architectures	188-190
5.3 Comparative analysis of electrochemical sensing architectures	190-192
5.4 Overall comparison of all reported sensing methods	192-195
References	195-198
 CHAPTER 6: Conclusion and future prospects	 [199-206]
6.1 Conclusion	200-204
6.2 Future prospect	204-206
 List of Publications	 [207-212]