INDEX

1. INTRODUCTION 3
   1.1. CITRUS 3
   1.2. INTEGRATED PEST MANAGEMENT IN SPANISH CITRUS 4
      1.2.1. Primary citrus pests in Spain and their management 4
      1.2.2. Aphids as citrus pests 6
   1.3. APHIS SPIRAECOLA AS A CITRUS PEST 8
      1.3.1. Origin and geographical distribution 8
      1.3.2. Morphological description 9
      1.3.3. Life cycle 10
      1.3.4. Seasonal abundance 11
      1.3.5. Ecology 12
      1.3.6. Damages and economic thresholds 13
   1.4. INTEGRATED MANAGEMENT OF APHIS SPIRAECOLA IN CLEMENTINE CITRUS 15
      1.4.1. Chemical control 15
      1.4.2. Cultural control 16
      1.4.3. Biological control 17
         1.4.3.1. Parasitoids 17
         1.4.3.2. Predators 21
   1.5. RATIONALE AND OBJECTIVES 30
      1.5.1. Poor performance of parasitism 30
      1.5.2. Asynchrony between aphids and predators 31
      1.5.3. Cover management as conservation biological control of aphids in citrus 32
REFERENCES 34

2. UNTANGLING THE APHID-PARASITOID FOOD WEB IN CITRUS: CAN HYPERPARASITOIDS DISRUPT BIOLOGICAL CONTROL? 53

2.1. INTRODUCTION 55

2.2. MATERIAL AND METHODS 59

2.2.1. Experimental site and sampling dates 59

2.2.2. Field sampling 59

2.2.2.1. Parasitism rates 59

2.2.2.2. Parasitoid complex 60

2.2.3. Molecular identification 60

2.2.3.1. DNA sequencing of adult specimens and design of multiplex qPCR primers 60

2.2.3.2. Multiplex qPCR assay of aphid mummies 65

2.2.4. Secondary sex ratio 66

2.3. RESULTS 66

2.3.1. Parasitism rate 66

2.3.2. Primary parasitoid and hyperparasitoid complex 68

2.3.2.1. Emergence and morphological identification assay 70

2.3.2.2. Quantitative PCR assay 70

2.3.3. Seasonal trend 74

2.3.4. Hyperparasitism effect on the primary parasitoid sex ratio 75

2.4. DISCUSSION 78

REFERENCES 85
3. EARLY ARRIVAL OF PREDATORS CONTROLS APHIS SPIRAECOLA COLONIES IN CITRUS CLEMENTINES. 97

3.1. INTRODUCTION 99

3.2. MATERIALS AND METHODS 102

3.2.1. Study orchards 102

3.2.2. Aphid colonies and predators 103

3.2.3. Damage and intervention thresholds 104

3.2.4. Data analysis 105

3.3. RESULTS 106

3.3.1. Colony parameters 106

3.3.1.1. Maximum number of aphids per colony 106

3.3.1.2. Colony survival 107

3.3.1.3. Colony phenology 109

3.3.2. Aphid predators 111

3.3.2.1. Abundance of aphid predators 111

3.3.2.2. Attack ratio and time of the first attack by aphid predators 113

3.3.3. Effect of the first attack by predators on colony parameters and damages 114

3.4. DISCUSSION 117

REFERENCES 123

4. A SOWN COVER WITH WILD PLANTS IMPROVES THE BIOLOGICAL CONTROL OF APHIDS IN CITRUS. 133

4.1. INTRODUCTION 135

4.2. MATERIAL AND METHODS 138
4.2.1. Orchards  138
4.2.2. Ground cover sampling  139
4.2.3. Citrus canopy sampling  141
4.2.4. Statistical analysis  143

4.3. RESULTS  144
4.3.1. Ground cover characterization  144
4.3.2. Aphid community in the ground cover  145
   4.3.2.1. Quantitative analysis  145
   4.3.2.2. Qualitative analysis  146
4.3.3. The effect of ground cover on aphid natural enemies in the canopy  153
   4.3.3.1. Ratio of attacked colonies  153
   4.3.3.2. Cumulative predators and parasitoids per day  154
4.3.4. Aphid damage  156

4.4. DISCUSSION  157

REFERENCES  163

5. GENERAL DISCUSSION AND CONCLUSIONS  173
REFERENCES  179