

# Table of Content

|                                                                  |            |
|------------------------------------------------------------------|------------|
| <b>Acknowledgments</b> .....                                     | <b>iii</b> |
| <b>Table of Content</b> .....                                    | <b>iv</b>  |
| <b>List of Tables</b> .....                                      | <b>vii</b> |
| <b>List of Figures</b> .....                                     | <b>ix</b>  |
| <b>Abbreviations</b> .....                                       | <b>xi</b>  |
| <b>1 Introduction</b> .....                                      | <b>1</b>   |
| 1.1 Relevance of potato production in Germany.....               | 1          |
| 1.2 Factors affecting the quality of potato chips.....           | 2          |
| 1.3 Factors affecting the internal quality of potato tubers..... | 4          |
| 1.4 The importance of calcium for the plant and plant cell ..... | 7          |
| 1.5 Calcium fertilizer and calcium uptake of potato tuber.....   | 9          |
| 1.6 Aims of the research and outline of the thesis .....         | 11         |
| References .....                                                 | 11         |
| <b>2 Material and methods</b> .....                              | <b>18</b>  |
| 2.1 Material .....                                               | 18         |
| 2.2 Field experiment.....                                        | 18         |
| 2.2.1 Field experiment 2001 .....                                | 19         |
| 2.2.2 Field experiment 2002 and 2003 .....                       | 19         |
| 2.3 Storage conditions and potato sample preparation.....        | 20         |
| 2.4 Soil analysis .....                                          | 20         |
| 2.4.1 Soil solution displacement.....                            | 20         |
| 2.4.2 Determination of exchangeable soil nutrients .....         | 21         |
| 2.5 Tuber Analysis.....                                          | 22         |
| 2.5.1 Determination of dry matter content.....                   | 22         |
| 2.5.2 Determination of L-ascorbic acid .....                     | 22         |
| 2.5.3 Determination of citric acid .....                         | 23         |
| 2.5.4 Determination of chlorogenic acid .....                    | 23         |
| 2.5.5 Potato chip producing and color measurement.....           | 24         |
| 2.5.6 Determination of starch .....                              | 24         |
| 2.5.7 Determination of amylose and amylopectin ratio .....       | 25         |

|          |                                                                                                                       |           |
|----------|-----------------------------------------------------------------------------------------------------------------------|-----------|
| 2.5.8    | Enzymatic determination of sugars.....                                                                                | 26        |
| 2.5.9    | Determination of micro- and macronutrients.....                                                                       | 27        |
| 2.5.10   | Determination of nitrogen.....                                                                                        | 28        |
| 2.5.11   | Free amino acid determination.....                                                                                    | 28        |
| 2.5.12   | Investigation of pasting properties of potato flour and starch.....                                                   | 29        |
|          | References.....                                                                                                       | 30        |
| <b>3</b> | <b>Effect of calcium fertilizers on mineral composition and occurrence of brown centre in potato tubers.....</b>      | <b>32</b> |
| 3.1      | Introduction.....                                                                                                     | 32        |
| 3.2      | Material and methods.....                                                                                             | 34        |
| 3.2.1    | Field experiment.....                                                                                                 | 34        |
| 3.2.2    | Soil analysis.....                                                                                                    | 35        |
| 3.2.3    | Brown centre determination.....                                                                                       | 36        |
| 3.2.4    | Statistical analysis.....                                                                                             | 37        |
| 3.3      | Results.....                                                                                                          | 37        |
| 3.3.1    | Yield and size of tuber.....                                                                                          | 37        |
| 3.3.2    | Soil Analysis.....                                                                                                    | 39        |
| 3.3.3    | Tubers mineral composition.....                                                                                       | 42        |
| 3.3.4    | Effect of nitrogen fertilizers.....                                                                                   | 49        |
| 3.3.5    | The occurrence of brown centre.....                                                                                   | 50        |
| 3.4      | Discussion.....                                                                                                       | 52        |
| 3.5      | Conclusion.....                                                                                                       | 55        |
|          | References.....                                                                                                       | 56        |
| <b>4</b> | <b>Effect of calcium fertilization, year, and location on internal quality of fresh and stored potato tubers.....</b> | <b>59</b> |
| 4.1      | Introduction.....                                                                                                     | 59        |
| 4.2      | Material and methods.....                                                                                             | 60        |
| 4.3      | Results and discussion.....                                                                                           | 62        |
| 4.3.1    | Tuber dry matter.....                                                                                                 | 62        |
| 4.3.2    | Starch.....                                                                                                           | 63        |
| 4.3.3    | Sucrose and reducing sugars.....                                                                                      | 65        |
| 4.3.4    | Crude protein and free amino acids composition.....                                                                   | 69        |
| 4.3.5    | Organic acids.....                                                                                                    | 73        |
| 4.3.6    | Effect of year and location.....                                                                                      | 76        |
| 4.4      | Conclusion.....                                                                                                       | 78        |
|          | References.....                                                                                                       | 79        |

|          |                                                                                                                                                           |            |
|----------|-----------------------------------------------------------------------------------------------------------------------------------------------------------|------------|
| <b>5</b> | <b>Correlation analysis on nutrient composition of potato tubers fertilized with calcium in three years of field experiments and three locations.....</b> | <b>84</b>  |
| 5.1      | Introduction .....                                                                                                                                        | 84         |
| 5.2      | Material and methods .....                                                                                                                                | 85         |
| 5.3      | Results and discussion.....                                                                                                                               | 86         |
| 5.3.1    | Mineral nutrients in the potato tuber .....                                                                                                               | 86         |
| 5.3.2    | Relationship between quality parameters of potato tubers.....                                                                                             | 90         |
| 5.3.3    | Relationship between mineral nutrients and quality parameters of potato tubers .....                                                                      | 94         |
| 5.4      | Conclusion .....                                                                                                                                          | 96         |
|          | References .....                                                                                                                                          | 96         |
| <b>6</b> | <b>Effect of calcium fertilizer on color quality of potato chips .....</b>                                                                                | <b>101</b> |
| 6.1      | Introduction .....                                                                                                                                        | 101        |
| 6.2      | Material and methods .....                                                                                                                                | 102        |
| 6.3      | Results and discussion.....                                                                                                                               | 103        |
| 6.3.1    | Effect of calcium fertilization .....                                                                                                                     | 103        |
| 6.3.2    | Factors affecting the color quality of chips .....                                                                                                        | 107        |
| 6.4      | Conclusion .....                                                                                                                                          | 110        |
|          | References .....                                                                                                                                          | 110        |
| <b>7</b> | <b>Pasting properties of potato flour and starch from potatoes fertilized with calcium .....</b>                                                          | <b>113</b> |
| 7.1      | Introduction .....                                                                                                                                        | 113        |
| 7.2      | Material and methods .....                                                                                                                                | 114        |
| 7.3      | Results and discussion.....                                                                                                                               | 117        |
|          | References .....                                                                                                                                          | 125        |
| <b>8</b> | <b>General conclusion .....</b>                                                                                                                           | <b>129</b> |
|          | Future study.....                                                                                                                                         | 131        |
|          | References .....                                                                                                                                          | 131        |

## List of Tables

|          |                                                                                                                                              |    |
|----------|----------------------------------------------------------------------------------------------------------------------------------------------|----|
| Table 1  | Properties of the soil .....                                                                                                                 | 36 |
| Table 2  | Initial soil test values of pH and exchangeable cations in the plow layer (0 – 30 cm depth).....                                             | 36 |
| Table 3  | Effect of calcium fertilizer on yield and tuber size of potatoes from planting season 2002 .....                                             | 38 |
| Table 4  | Effect of calcium fertilizer on yield and tuber size of potatoes from planting season 2003 .....                                             | 38 |
| Table 5  | Mean square analysis of calcium concentration in soil solution and exchangeable calcium at the onset of tuberization and after harvest ..... | 40 |
| Table 6  | Macroelements concentration in potato tuber parenchyma and periderm and mean square analysis from planting season 2002 .....                 | 44 |
| Table 7  | Macroelements concentration in potato tuber parenchyma and periderm and mean square analysis from planting season 2003 .....                 | 45 |
| Table 8  | Microelement concentration in potato tuber parenchyma and periderm and mean square analysis from planting season 2002 .....                  | 46 |
| Table 9  | Microelement concentration in potato tuber parenchyma and periderm and mean square analysis from planting season 2003 .....                  | 47 |
| Table 10 | Effect of nitrogen fertilizers and application methods on tuber Ca concentration from planting season 2001.....                              | 50 |
| Table 11 | Effect of different sources of nitrogen on calcium concentration in soil solution and in potato tubers from planting season 2002.....        | 50 |
| Table 12 | Precipitation rate, sunshine length, and temperature during planting seasons 2001 to 2003 <sup>a</sup> .....                                 | 61 |
| Table 13 | Effect of calcium fertilization and storage on free amino acids and amides compositions of potato tubers from planting season 2002.....      | 71 |
| Table 14 | Effect of calcium fertilization and storage on free amino acids and amides compositions of potato tubers from planting season 2003.....      | 72 |
| Table 15 | Quality parameters of potato tubers from different locations and planting seasons .....                                                      | 77 |

|           |                                                                                                                                                                                                            |     |
|-----------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----|
| Table 16  | Mean, standard deviation, minimum, and maximum concentrations of macro- and microelements as well as ratio of mineral concentration in tuber parenchyma and periderm and the correlation between them..... | 87  |
| Table 17  | Correlation matrix between mineral nutrients in potato tuber parenchyma .....                                                                                                                              | 88  |
| Table 18  | Correlation matrix between mineral nutrients in potato tuber periderm.....                                                                                                                                 | 89  |
| Table 19  | Mean, standard deviation, minimum and maximum concentrations of potato tubers' quality parameters.....                                                                                                     | 90  |
| Table 20  | Correlation matrix between quality parameters of potato tubers.....                                                                                                                                        | 91  |
| Table 21  | Mean, standard deviation, minimum, and maximum concentration of free amino acids in the potato tuber .....                                                                                                 | 92  |
| Table 22  | Correlation matrix between free amino acids of potato tubers.....                                                                                                                                          | 93  |
| Table 23  | Correlation between mineral nutrients and quality parameters of fresh potato tubers .....                                                                                                                  | 94  |
| Table 24. | Correlation between mineral nutrients and free amino acids of potato tubers .....                                                                                                                          | 95  |
| Table 25  | Analysis of variance of lightness of potato chips from the planting seasons 2001, 2002, and 2003 .....                                                                                                     | 104 |
| Table 26  | Effect of calcium fertilization on pasting properties of potato flour .....                                                                                                                                | 119 |
| Table 27  | Effect of calcium fertilization, rate of application, and location on pasting properties of potato starch from tubers before storage as well as analysis of variance F ratio and root mean square.....     | 120 |
| Table 28  | Change in pasting properties of starch from stored potato tubers.....                                                                                                                                      | 122 |
| Table 29  | Correlation matrix between mineral nutrients of potato tubers and pasting properties of potato starch before storage .....                                                                                 | 123 |
| Table 30  | Stepwise multiple regression analysis of pasting properties of potato starch with mineral content of potato tubers.....                                                                                    | 125 |

## List of Figures

|           |                                                                                                                                                                                                                             |    |
|-----------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----|
| Figure 1  | Relationship between exchangeable calcium and calcium concentration of potato tuber periderm from previous studies .....                                                                                                    | 10 |
| Figure 2  | Displacement of soil solution according to the method described by Adams (1974) .....                                                                                                                                       | 21 |
| Figure 3  | Standard curve for the determination of amylose and amylopectin ratio .....                                                                                                                                                 | 26 |
| Figure 4  | Effect of calcium fertilization on soil pH from planting seasons 2002 and 2003.....                                                                                                                                         | 39 |
| Figure 5  | Effect of calcium fertilization on calcium concentration in soil solution and exchangeable calcium.....                                                                                                                     | 41 |
| Figure 6. | Relative tuber calcium as a function of relative calcium concentration in soil solution during tuber growth fertilized with CaCO <sub>3</sub> (black) and gypsum (grey) from planting season 2002 .....                     | 48 |
| Figure 7. | Relative tuber calcium as a function of relative calcium concentration in soil solution during tuber growth fertilized with CaCO <sub>3</sub> (black), gypsum (grey), and basic slag (white) from planting season 2003..... | 48 |
| Figure 8  | Brown centre inside potato tuber .....                                                                                                                                                                                      | 51 |
| Figure 9  | Relationship between calcium and potassium concentration in tuber parenchyma with occurrence of internal brown centre.....                                                                                                  | 52 |
| Figure 10 | Effect of calcium fertilization on dry matter content of potato tubers during storage .....                                                                                                                                 | 62 |
| Figure 11 | Effect of calcium fertilization on starch concentration of potato tubers before storage.....                                                                                                                                | 64 |
| Figure 12 | Effect of calcium fertilization on starch concentrations in potato tubers during storage .....                                                                                                                              | 65 |
| Figure 13 | Effect of calcium fertilization on sucrose concentrations in potato tubers before storage.....                                                                                                                              | 66 |
| Figure 14 | Effect of calcium fertilization on sucrose concentrations in potato tubers during storage from planting season 2002.....                                                                                                    | 67 |
| Figure 15 | Effect of calcium fertilization on the reducing sugars concentrations in potato tubers before storage. ....                                                                                                                 | 68 |
| Figure 16 | Effect of calcium fertilization on reducing sugars concentrations in tubers during storage .....                                                                                                                            | 69 |
| Figure 17 | Effect of calcium fertilization on crude protein concentrations in potato tubers before and after seven months storage.....                                                                                                 | 70 |

|           |                                                                                                                                                                                 |     |
|-----------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----|
| Figure 18 | Effect of calcium fertilization on L-ascorbic acid (a) and citric acid (b) concentrations in potato tubers during storage. ....                                                 | 74  |
| Figure 19 | Effect of calcium fertilization on chlorogenic acid concentrations in potato tubers before storage .....                                                                        | 75  |
| Figure 20 | Effect of calcium fertilization on chlorogenic acid concentrations in potato tubers during storage.....                                                                         | 76  |
| Figure 21 | Comparison between lightness values of light and dark potato chips.....                                                                                                         | 105 |
| Figure 22 | Change in lightness of potato chips from untreated potato tubers (control treatment) during storage.....                                                                        | 105 |
| Figure 23 | Relative change of lightness of potato chips made from fresh and stored potato tubers which were fertilized with gypsum and CaCO <sub>3</sub> in the planting season 2001 ..... | 106 |
| Figure 24 | Relative change in lightness of potato chips made from fresh and stored potato tubers which were fertilized with gypsum and CaCO <sub>3</sub> in the planting season 2002 ..... | 106 |
| Figure 25 | Relative change in lightness of potato chips made from fresh and stored potato tubers which were fertilized with gypsum and CaCO <sub>3</sub> in the planting season 2003 ..... | 106 |
| Figure 26 | Correlation of D-glucose, D-fructose, reducing sugars (the sum of D-glucose and D-fructose), sucrose, ascorbic acid, and chlorogenic acid with lightness of potato chips.....   | 109 |
| Figure 27 | Correlation between free amino acids and lightness of potato chips.....                                                                                                         | 110 |
| Figure 28 | Effect of calcium fertilization on starch content of tubers grown in Langwedel and Hankensbuettel.....                                                                          | 117 |
| Figure 29 | Effect of calcium fertilization on percentage of amylose in potato starch from potato tubers grown in Hankensbuettel .....                                                      | 118 |
| Figure 30 | Size distribution of starch granules from potato tubers grown in Langwedel and Hankensbuettel.....                                                                              | 121 |

## Abbreviations

|                  |                                                        |
|------------------|--------------------------------------------------------|
| AA               | Amino acid                                             |
| Abs              | Absorbance                                             |
| ATP              | Adenosine triphosphate                                 |
| df               | Degree of freedom                                      |
| DIP              | 2,6-dichlorophenol indophenol                          |
| DM               | Dry matter                                             |
| FW               | Fresh weight                                           |
| GO               | Gross Oesingen                                         |
| HKB              | Hankensbuettel                                         |
| PEP              | Phospho-enol-Pyruvate                                  |
| KAS              | Ammonium nitrate with lime                             |
| KS               | Calcium nitrate                                        |
| LGW              | Langwedel                                              |
| Max              | Maximum                                                |
| Min              | Minimum                                                |
| MS               | Mean square                                            |
| NADH             | Nicotinamide adenine dinucleotide                      |
| NADPH            | Nicotinamide adenine dinucleotide phosphate            |
| N <sub>min</sub> | Nitrogen in mineral form                               |
| OPA              | O-phthaldialdehyde                                     |
| R                | Pearson's coefficient of correlation                   |
| R <sup>2</sup>   | Coefficient determination                              |
| RH               | Relative humidity                                      |
| RP-HPLC          | Reverse phase – high performance liquid chromatography |
| Stdv             | Standard deviation                                     |
| s.e.             | Standard error                                         |
| uv               | Ultra violet                                           |

### Amino acids:

|     |               |
|-----|---------------|
| Ala | Alanine       |
| Arg | Arginine      |
| Asn | Asparagine    |
| Asp | Aspartic acid |
| Gln | Glutamine     |
| Glu | Glutamic acid |
| Gly | Glycine       |
| His | Histidine     |
| Ile | Isoleucine    |
| Leu | Leucine       |
| Lys | Lysine        |
| Met | Methionine    |
| Phe | Phenylalanine |



|     |           |
|-----|-----------|
| Ser | Serine    |
| Thr | Threonine |
| Tyr | Tyrosine  |
| Val | Valine    |

**Units:**

|     |                                  |
|-----|----------------------------------|
| °C  | degree Celcius                   |
| cm  | centimeter                       |
| g   | gram                             |
| ha  | hectare                          |
| kg  | kilogram                         |
| km  | kilometer                        |
| L   | Liter                            |
| L*  | Lightness unit based on CIE 1976 |
| m   | meter                            |
| M   | molar                            |
| mg  | milligram                        |
| Mg  | megagram                         |
| mL  | milliliter                       |
| min | minute                           |
| mm  | millimeter                       |
| μ   | Micro                            |
| N   | Normality                        |
| RVU | rapid visco unit                 |
| Tg  | Terragram                        |
| v/v | volume per volume                |

**Elements:**

|    |            |
|----|------------|
| B  | Boron      |
| Ca | Calcium    |
| Cu | Copper     |
| Fe | Iron       |
| H  | Hydrogen   |
| I  | Iodine     |
| K  | potassium  |
| Mg | Magnesium  |
| Mn | Manganese  |
| Mo | Molybdenum |
| N  | Nitrogen   |
| Na | Sodium     |
| O  | Oxygen     |
| P  | Phosphorus |
| S  | Sulphur    |
| Zn | Zinc       |