

Contents

Preface to the Third Edition	xvii
List of Contributors	xix
1 History and Future of Starch	1
I. History	1
1. Early History	1
2. 1500–1900	2
3. 1900–Present	4
II. Development of Specialty Starches	5
1. Waxy Corn Starch	5
2. High-amylose Corn Starch	5
3. Chemically Modified Starches	6
4. Other Naturally Modified Corn Starches	6
III. Other Products from Starch	6
1. Sweeteners	6
2. Ethanol	7
3. Polyols	8
4. Organic Acids	8
5. Amino Acids	8
IV. Future of Starch	9
1. Two New Starches for Industry	9
2. Present American Companies	9
V. References	10
2 Economic Growth and Organization of the US Corn Starch Industry	11
I. Introduction	11
II. Extent and Directions of Market Growth	11
III. High-fructose Syrup Consumption	13
IV. Fuel Alcohol	15
V. Technical Progress	16
VI. Plant Location	16
VII. Industry Organization	16
VIII. Effects of Corn Price Variability	18
IX. International Involvement	19
X. Future Industry Prospects	20
XI. References	20

3	Genetics and Physiology of Starch Development.	23
	I. Introduction	24
	II. Occurrence	25
	1. General Distribution	25
	2. Cytosolic Starch Formation	25
	3. Starch Formed in Plastids	26
	III. Cellular Developmental Gradients	26
	IV. Non-mutant Starch Granule Polysaccharide Composition	28
	1. Polysaccharide Components	28
	2. Species and Cultivar Effects on Granule Composition	30
	3. Developmental Changes in Granule Composition	31
	4. Environmental Effects on Granule Composition	32
	V. Non-mutant Starch Granule and Plastid Morphology	33
	1. Description	33
	2. Species and Cultivar Effects on Granule Morphology	33
	3. Developmental Changes in Average Starch Granule Size	34
	4. Formation and Enlargement of Non-mutant Granules	34
	VI. Polysaccharide Biosynthesis	36
	1. Enzymology	36
	2. Compartmentation and Regulation of Starch Synthesis and Degradation in Chloroplasts	37
	3. Compartmentation and Regulation of Starch Synthesis in Amyloplasts	40
	VII. Mutant Effects	43
	1. Waxy	44
	2. Amylose-extender.	50
	3. Sugary	53
	4. Sugary-2	56
	5. Dull	57
	6. Amylose-extender Waxy	58
	7. Amylose-extender Sugary	59
	8. Amylose-extender Sugary-2	60
	9. Amylose-extender Dull	61
	10. Dull Sugary	61
	11. Dull Sugary-2	62
	12. Dull Waxy	62
	13. Sugary Waxy	63
	14. Sugary-2 Waxy	63
	15. Sugary Sugary-2	64
	16. Amylose-extender Dull Sugary	64
	17. Amylose-extender Dull Sugary-2	65
	18. Amylose-extender Dull Waxy	65
	19. Amylose-extender Sugary Sugary-2	66
	20. Amylose-extender Sugary Waxy	66
	21. Amylose-extender Sugary-2 Waxy	67
	22. Dull Sugary Sugary-2	67
	23. Dull Sugary Waxy	67
	24. Dull Sugary-2 Waxy	68

25. Sugary Sugary-2 Waxy	68
26. Amylose-extender Dull Sugary Waxy	68
VIII. Conclusions	69
IX. References	71
4 Biochemistry and Molecular Biology of Starch Biosynthesis	83
I. Introduction	84
II. Starch Synthesis in Plants: Localization	84
1. Leaf Starch	84
2. Starch in Storage Tissues	85
III. Enzyme-catalyzed Reactions of Starch Synthesis in Plants and Algae and Glycogen Synthesis in Cyanobacteria	85
IV. Properties of the Plant 1,4- α -Glucan-Synthesizing Enzymes	87
1. ADP-glucose Pyrophosphorylase: Kinetic Properties and Quaternary Structure	87
2. Relationship Between the Small and Large Subunits: Resurrection of ADPGlc PPase Catalysis in the Large Subunit	91
3. Phylogenetic Analysis of the Large and Small Subunits	95
4. Crystal Structure of Potato Tuber ADPGlc PPase	95
5. Supporting Data for the Physiological Importance of Regulation of ADPGlc PPase	104
6. Differences in Interaction Between 3PGA and Pi in Different ADPGlc PPases	105
7. Plant ADPGlc PPases can be Activated by Thioredoxin	107
8. Characterization of ADPGlc PPases from Different Sources	108
9. Identification of Important Amino Acid Residues Within the ADPGlc PPases	111
10. Starch Synthase	114
11. Branching Enzyme	129
12. Other Enzymes Involved in Starch Synthesis	136
V. Abbreviations	138
VI. References	139
5 Structural Features of Starch Granules I	149
I. Introduction	149
II. Granule Architecture	153
1. An Overview of Granule Structure	153
2. Molecular Organization of Crystalline Structures	153
3. Crystalline Ultrastructural Features of Starch	158
4. The Supramolecular Organization of Starch Granules	160
III. The Granule Surface	167
1. Starch Granule Surface and Chemistry and Composition	168
2. Surface-Specific Chemical Analysis	169
IV. Granule Surface Imaging	170
1. Granule Imaging by SEM Methods	170
2. Principles of AFM	171
3. Sample Preparation for AFM Imaging of Granular Starch	172
4. Surface Detail and Inner Granule Structure Revealed by AFM	173
5. Interpretation of AFM Images with Respect to Granule Structure ..	175

6.	Discussion of Granule Surface Imaging by Scanning Probe Microscopy (SPM)	177
7.	Future Prospects of SPM of Starch	179
V.	A Hypothesis of Starch Granule Structure: The Blocklets Concept	180
VI.	Location and State of Amylose Within Granules	184
VII.	Surface Pores and Interior Channels of Starch Granules	186
VIII.	Conclusions	187
IX.	References	188
6	Structural Features of Starch Granules II	193
I.	Introduction	193
II.	General Characteristics of Starch Granules	194
1.	Granule Shapes, Sizes and Distributions	194
2.	Porous Structures of Starch Granules	195
3.	Shapes of Gelatinized Starch Granules	200
III.	Molecular Compositions of Starch Granules	201
1.	Amylopectin and Amylose	201
2.	Intermediate Material and Phytoglycogen	202
3.	Lipids and Phospholipids	204
4.	Phosphate Monoesters	205
IV.	Structures of Amylose and Amylopectin	205
1.	Chemical Structure of Amylose	205
2.	Single Helical Structures (V-Complexes) of Amylose	208
3.	Double Helical Structures of Amylose	211
4.	Chemical Structure of Amylopectin	212
5.	Cluster Models of Amylopectin	218
6.	Effects of Growing Temperature and Kernel Maturity on Starch Structures	224
V.	Locations of Molecular Components in the Granule	225
VI.	References	227
7	Enzymes and Their Action on Starch	237
I.	Introduction	238
II.	Amylases	238
1.	Action of Endo-Acting α -Amylases	238
2.	Action of Exo-Acting β -Amylases	244
3.	Amylases Producing Specific Maltodextrin Products	246
4.	Action of Isoamylases	247
5.	Archaeobacterial Amylases	248
6.	Action of Cyclomaltodextrin Glucanotransferase	250
III.	Relation of Structure with Action of the Enzymes	253
1.	Relation of Structure with Action of Endo-Acting α -Amylases	253
2.	Structure and Action of Soybean β -Amylase	257
3.	Structure and Action of Glucoamylases	257
4.	Specific Amino Acids at the Active-Site Involved in Catalysis and Substrate Binding	261
5.	Structure and Function of Domains in Amylolytic Enzymes	262
IV.	Mechanisms for the Enzymatic Hydrolysis of the Glycosidic Bond	264
V.	Action of Amylases on Insoluble Starch Substrates	267

1.	Action of α -Amylases on Amylose-V Complexes and Retrograded Amylose	267
2.	Action of Amylases with Native Starch Granules	269
VI.	Inhibitors of Amylase Action	272
VII.	Action of Phosphorylase and Starch Lyase	276
1.	Plant Phosphorylase	276
2.	Starch Lyase	277
VIII.	Enzymic Characterization of Starch Molecules	278
1.	Determination of the Nature of the Branch Linkage in Starch	279
2.	Identification and Structure Determination of Slightly Branched Amyloses	280
3.	Formation of β -Amylase Limit Dextrins of Amylopectin and Determination of their Fine Structure	282
IX.	References	284
8	Structural Transitions and Related Physical Properties of Starch.	293
I.	Introduction	293
II.	Starch Structure, Properties and Physical Methods of Analysis	295
1.	Ordered and Amorphous Structural Domains (See Also Chapters 5 and 6)	296
2.	Physical Properties of Starch in Water	301
III.	State and Phase Transitions	310
3.	Glass Transitions of Amorphous Structural Domains	311
4.	Annealing and Structural Modifications by Heat-Moisture Treatments	320
5.	Melting Transitions of Crystallites in Granular Starch	323
6.	Gelation and Retrogradation of Starch and its Polymeric Components	332
7.	Phase Transitions and Other Properties of V-Structures	354
IV.	References	359
9	Corn and Sorghum Starches: Production	373
I.	Introduction	374
II.	Structure, Composition and Quality of Grain	375
1.	Structure	376
2.	Composition	381
3.	Grain Quality	385
III.	Wet-milling	391
1.	Grain Cleaning	392
2.	Steeping	394
3.	Milling and Fraction Separation	408
4.	Starch Processing	421
5.	Product Drying, Energy Use and Pollution Control	421
6.	Automation	423
IV.	The Products	423
1.	Starch	423
2.	Sweeteners	423
3.	Ethanol	424
4.	Corn Oil	425
5.	Feed Products	426

V.	Alternative Fractionation Procedures	427
VI.	Future Directions in Starch Manufacturing.	429
	1. Continued Expansion into Fermentation Products	429
	2. Biosolids as Animal Food	429
	3. Processing of Specific Hybrids.	430
	4. New Corn Genotypes and Phenotypes via Biotechnology and Genetic Engineering.	430
	5. Segregation of the Corn Starch Industry	430
VII.	References	431
10	Wheat Starch: Production, Properties, Modification and Uses	441
	I. Introduction	442
	II. Production	442
	III. Industrial Processes for Wheat Starch Production	444
	1. Conventional Processes.	446
	2. Hydrocyclone Process (Dough-Batter)	448
	3. High-pressure Disintegration Process	450
	IV. Properties of Wheat Starch and Wheat Starch Amylose and Amylopectin	451
	1. Large Versus Small Granules	452
	2. Fine Structures of Amylose and Amylopectin.	457
	3. Partial Waxy and Waxy Wheat Starches	465
	4. High-amylose Wheat Starch	470
	5. A Unique Combination of Properties	471
	V. Modification of Wheat Starch	475
	1. Crosslinking.	475
	2. Substitution.	478
	3. Dual Derivatization	479
	4. Bleaching, Oxidation and Acid-thinning	480
	VI. Uses of Unmodified and Modified Wheat Starches	481
	1. Role in Baked Products	481
	2. Functionality in Noodles and Pasta.	485
	3. Other Food Uses	488
	4. Industrial Uses.	489
	VII. References	491
11	Potato Starch: Production, Modifications and Uses	511
	I. History of Potato Processing in The Netherlands	512
	II. Starch Production.	514
	1. World Starch Production	514
	2. Potato Starch Production in Europe	514
	III. Structure and Chemical Composition of the Potato.	515
	1. Formation and Morphology of the Tuber	515
	2. Anatomy of the Tuber	516
	3. Chemical Composition	518
	4. Differences Between Commercial Starches	519
	5. New Development: The All-amylopectin Potato	521
	IV. Potato Starch Processing	522
	1. Grinding	525

2. Potato Juice Extraction	525
3. Fiber Extraction	526
4. Starch Classification	527
5. Starch Refinery	529
6. Sideline Extraction	530
7. Removal of Water from the Starch	532
8. Starch Drying and Storage	533
V. Potato Protein	534
1. Environmental Aspects	534
2. Protein Recovery	535
3. Properties and Uses	535
VI. Utilization	535
1. Substitution (See Also Chapters 17 and 20)	535
2. Converted Starches (See Also Chapters 17 and 20)	536
3. Crosslinked Starches (See Also Chapters 17 and 20)	536
4. The Preference for Potato Starch in Applications	537
VII. Future Aspects of Potato Starch Processing	538
VIII. References	538
12 Tapioca/Cassava Starch: Production and Use	541
I. Background	541
II. Processing	545
III. Tapioca Starch	550
IV. Modification	555
V. Food Applications	556
VI. Industrial Applications	563
VII. Outlook	564
VIII. References	564
13 Rice Starches: Production and Properties	569
I. Rice Production and Composition	569
1. Rice Production	569
2. Rice Milling and Composition	570
II. Uses of Milled Rice and Rice By-products	571
1. Milled Rice	571
2. By-products	572
III. Preparation of Rice Starch	573
1. Traditional Method	573
2. Mechanical Method	574
IV. Properties of Rice Starch	574
1. General Properties Unique to Rice Starch	574
2. Pasting Properties	575
V. Factors Affecting Rice Starch Properties	575
1. Rice Variety: Common Versus Waxy	575
2. Protein Content	576
3. Method of Preparation	576
4. Modification	577
VI. Rice Starch Applications	577
VII. References	578

14	Rye Starch	579
	I. Introduction	579
	II. Isolation	580
	1. Industrial	580
	2. Laboratory	580
	III. Modification	582
	IV. Applications	582
	V. Properties	582
	1. Microscopy	582
	2. Composition	583
	3. X-Ray Diffraction Patterns	584
	4. Gelatinization Behavior	584
	5. Retrogradation	584
	6. Amylose-Lipid Complex	584
	7. Swelling Power and Amylose Leaching	584
	8. Rheology	585
	9. Falling Number	586
	VI. References	586
15	Oat Starch	589
	I. Introduction	589
	II. Isolation	589
	1. Industrial	590
	2. Laboratory	590
	III. Modification	591
	IV. Applications	591
	V. Properties of Oat Starch	591
	1. Microscopy	591
	2. Chemical Composition	592
	3. X-Ray Diffraction	594
	4. Gelatinization	594
	5. Retrogradation	595
	6. Swelling Power and Amylose Leaching	596
	7. Rheological Properties	597
	VI. References	598
16	Barley Starch: Production, Properties, Modification and Uses	601
	I. Introduction	601
	II. Barley Grain Structure and Composition	602
	III. Barley Starch	604
	1. Isolation and Purification	604
	2. Chemical Composition of Barley Starch	605
	3. Granule Morphology	607
	4. X-Ray Diffraction and Relative Crystallinity	607
	5. Gelatinization	607
	6. Swelling Factor and Amylose Leaching	610
	7. Enzyme Susceptibility	612
	8. Acid Hydrolysis	613
	9. Pasting Characteristics	615

10. Retrogradation	618
11. Freeze-Thaw Stability	619
12. Chemical Modification	619
13. Physical Modification	621
IV. Resistant Barley Starch	621
V. Production and Uses of Barley Starch	623
VI. Conclusion	625
VII. References	625
17 Modification of Starches	629
I. Introduction	629
II. Cationic Starches	632
1. Dry or Solvent Cationization	633
2. Polycationic Starches	634
3. Amphoteric Starch or Starch-containing Systems	635
4. Cationic Starches with Covalently-reactive Groups	636
III. Starch Graft Polymers (See Also Chapter 19)	637
IV. Oxidation of Starch	638
V. Starch-based Plastics (See Also Chapter 19)	640
VI. Encapsulation/Controlled Release	642
VII. Physically Modified Starch	644
1. Granular Cold-Water-Swellable (CWS) and Cold-Water-Soluble Starch (Pregelatinized Granular Starch)	644
2. Starch Granule Disruption by Mechanical Force	646
VIII. Thermal Treatments	646
IX. Enzyme-catalyzed Modifications	647
X. References	648
18 Starch in the Paper Industry	657
I. Introduction to the Paper Industry	658
II. The Papermaking Process	660
III. Starch Consumption by the Paper Industry	662
IV. Starches for Use in Papermaking	663
1. Current Use	663
2. Recent Trends	665
V. Application Requirements for Starch	666
1. Viscosity Specifications	666
2. Charge Specifications	668
3. Retrogradation Control	669
4. Purity Requirements	671
VI. Dispersion of Starch	672
1. Delivery to the Paper Mill	672
2. Suspension in Water	673
3. Dispersion Under Atmospheric Pressure	674
4. Dispersion Under Elevated Pressure	674
5. Chemical Conversion	676
6. Enzymic Conversion	677
VII. Use of Starch in the Papermaking Furnish	681
1. The Wet End of the Paper Machine	681

2.	Flocculation of Cellulose Fibers and Fines	681
3.	Adsorption of Starch on Cellulose and Pigments	682
4.	Retention of Pigments and Cellulose Fines	683
5.	Sheet Bonding by Starch	684
6.	Wet-end Sizing	685
7.	Starch Selection for Wet-end Use	687
VIII.	Use of Starch for Surface Sizing of Paper	688
1.	The Size Press in the Paper Machine	688
2.	The Water Box at the Calender	693
3.	Spray Application of Starch	693
4.	Starch Selection for Surface Sizing	693
IX.	Use of Starch as a Coating Binder	695
1.	The Coater in the Paper Machine	695
2.	Starch Selection for Paper Coating	698
X.	Use of Starch as Adhesive in Paper Conversion	700
1.	Lamination of Paper	700
2.	The Corrugator for Paperboard	700
3.	Starch Selection for Use in Corrugation and Lamination	702
XI.	Use of Starch in Newer Specialty Papers	703
XII.	Environmental Aspects of Starch Use in the Paper Industry	703
XIII.	Starch Analysis in Paper	705
XIV.	References	706
19	Starch in Polymer Compositions	715
I.	Introduction	715
II.	Starch Esters	717
III.	Granular Starch Composites	719
IV.	Starch in Rubber	724
V.	Starch Graft Copolymers	726
VI.	Thermoplastic Starch Blends	731
VII.	Starch Foams	735
VIII.	References	737
20	Starch Use in Foods	745
I.	Introduction	746
1.	First Enhancement of Starch for Foods	747
2.	Modern Use of Starch in Foods	747
3.	Development of Crosslinking	747
4.	Development of Monosubstitution	747
5.	'Instant' Starches	748
6.	Improvement of Starch Sources (See Also Chapter 3)	748
II.	Functions of Starch in Food Applications	748
1.	Starch Structures Relevant to Foods	749
2.	Gelatinization and Pasting	749
3.	Changes During Cooking	750
III.	Impact of Processing and Storage on Foods	
	Containing Cooked Starch	751
1.	Concentration During Cooking	751
2.	Effects of Time and Temperature	751

3. Effects of Shear	752
4. Comparison of Food Processing Equipment	753
5. Impact of Processing and Storage	754
6. Changes that Occur During Cooling, Storage and Distribution	754
7. Recommended Processing	755
IV. Modified Food Starches (See Also Chapter 17)	756
1. Why Starch is Modified	756
2. Derivatizations	756
3. Conversions	760
4. Oxidation	761
5. Physical Modifications	762
6. Native Starch Thickeners	767
V. Starch Sources (See Also Chapters 9-16)	767
1. Dent Corn	768
2. Waxy Corn	768
3. High-amylose Corn	769
4. Tapioca	770
5. Potato	770
6. Wheat	770
7. Sorghum	771
8. Rice	771
9. Sago	772
10. Arrowroot	772
11. Barley	772
12. Pea	772
13. Amaranth	773
VI. Applications	773
1. Canned Foods	774
2. Hot-filled Foods	775
3. Frozen Foods	775
4. Salad Dressings	776
5. Baby Foods	777
6. Beverage Emulsions	777
7. Encapsulation	777
8. Baked Foods	778
9. Dry Mix Foods	778
10. Confections	778
11. Snacks and Breakfast Cereals	779
12. Meats	780
13. Surimi	781
14. Pet Food	781
15. Dairy Products	781
16. Fat Replacers	782
VII. Interactions with Other Ingredients	783
1. pH	783
2. Salts	783
3. Sugars	784
4. Fats and Surfactants	784

5. Proteins	785
6. Gums/hydrocolloids	786
7. Volatiles	786
8. Amylolytic Enzymes	786
VIII. Resistant Starch	787
IX. References	788
21 Sweeteners from Starch: Production, Properties and Uses	797
I. Introduction	797
1. History	797
2. Definitions	799
3. Regulatory Status	800
II. Production Methods	800
1. Maltodextrins	800
2. Glucose/corn Syrups	802
3. High-fructose Syrups	808
4. Crystalline Fructose	813
5. Crystalline Dextrose and Dextrose Syrups	813
6. Oligosaccharide Syrups	815
III. Composition and Properties of Sweeteners from Starch	817
1. Carbohydrate Profiles	817
2. Solids	818
3. Viscosity	819
4. Browning Reaction and Color	821
5. Fermentability	822
6. Foam Stabilization and Gel Strength	823
7. Freezing Point Depression	824
8. Boiling Point Elevation	824
9. Gelatinization Temperature	824
10. Humectancy and Hygroscopicity	825
11. Crystallization	826
12. Sweetness	827
13. Selection of Sweeteners	828
IV. References	829
22 Cyclodextrins: Properties and Applications	833
I. Introduction	833
II. Production	835
III. Properties	837
IV. Toxicity and Metabolism	838
V. Modified Cyclodextrins	840
1. Hydroxyalkylcyclodextrins	840
VI. Complex Formation	842
VII. Applications	845
VIII. References	848
Index	853