

RHEOLOGICAL STUDY ON ICE CREAM

By

YASSER FAROUK HASSAN ABD EL-GHANY

**B.Sc. Agric. Sci. (Dairy Science), Fac. Agric., Cairo Univ., 1993
M.Sc. Agric. Sci. (Dairy Science), Fac. Agric., El-Azhar Univ., 2002**

THESIS

**Submitted in Partial Fulfillment of the
Requirements for the Degree of**

DOCTOR OF PHILOSOPHY

In

**Agricultural Sciences
(Dairy Science)**

**Department of Dairy Science
Faculty of Agriculture
Cairo University
EGYPT**

2016

APPROVAL SHEET

RHEOLOGICAL STUDY ON ICE CREAM

**Ph.D. Thesis
In
Agric. Sci. (Dairy Science)**

By

YASSER FAROUK HASSAN ABD EL-GHANY
B.Sc. Agric. Sci. (Dairy Science), Fac. Agric., Cairo Univ., 1993
M.Sc. Agric. Sci. (Dairy Science), Fac. Agric., El-Azhar Univ., 2002

APPROVAL COMMITTEE

DR. REZK AZAB AWAD
Professor of Dairy Science, Fac. Agric., Ain Shams University

DR. MOHAMED AHMED ABD EL-KHALEK AZZAM
Professor of Dairy Science, Fac. Agric., Cairo University

DR. MONIER MAHMOUD IBRAHIM EL-ABD
Professor of Dairy Science, Fac. Agric., Cairo University

DR. HODA MAHMOUD MOHAMED EL-ZEINI
Professor of Dairy Science, Fac. Agric., Cairo University

Date : / /

SUPERVISION SHEET

RHEOLOGICAL STUDY ON ICE CREAM

**Ph.D. Thesis
In
Agric. Sci. (Dairy Science)**

By

YASSER FAROUK HASSAN ABD EL-GHANY
B.Sc. Agric. Sci. (Dairy Science), Fac. Agric., Cairo Univ., 1993
M.Sc. Agric. Sci. (Dairy Science), Fac. Agric., El-Azhar Univ., 2002

SUPERVISION COMMITTEE

DR. HODA MAHMOUD MOHAMED EL-ZEINI
Professor of Dairy Science, Fac. Agric., Cairo University

DR. MONIER MAHMOUD IBRAHIM EL-ABD
Professor of Dairy Science, Fac. Agric., Cairo University

DR. MOSTAFA ABD EL-MONEAM ZEDAN
Professor of Dairy Science, Food Technology Institute,
Agricultural Research Center. Ministry of Agriculture

Name of Candidate: Yasser Farouk Hassan Abd El-Ghany **Degree:** Ph.D.

Title of Thesis: Rheological study on ice cream

Supervisors: Dr. Hoda Mahmoud Mohamed El-Zeini

Dr. Monier Mahmoud Ibrahim El-Abd

Dr. Mostafa Abd El-Moneam Zedan

Department: Dairy Science

Branch:

Approval: 12 /5/ 2016

ABSTRACT

This work was implemented to study the effect of whey protein concentrate (WPC), whey protein isolate (WPI) and glycomacropeptide (GMP) as a partial substitution of milk solids not fat (MSNF) in ice cream formula by 1, 2, 3 and 4% of (MSNF). Mixes and resultant ice cream samples were analyzed for their chemical, physicochemical and rheological properties as well as the sensory quality attributes. There was no remarkable effect of adding whey proteins as partial substitution of MSNF on total solids or fat percentages, while total protein, ash, and lactose content were significantly affected. Specific gravity was significantly affected with the ratio of substitution in both mixes and resultant ice cream and therefore the weight per gallon and overrun percent were significantly changed in the samples. Apparent viscosity as well as flow time of mixes were significantly increased. Flow behavior was also affected showing higher yield stress. Increasing WPC, WPI and GMP in ice cream mixes resulted in a building up of structure leading to increase in the sample viscosity. The shear stress increased significantly with increasing the substitution ratio. Also, flow behavior index (n) decreased by increasing the substitution levels of whey proteins. The consistency coefficient (k) was more affected by the presence of whey proteins in the recipe than the flow behavior index. Herschel-Bulkley behavior (building up of structure and increasing of sample viscosity) was observed in ice cream mix by increasing the substitution levels of whey proteins. Back-extrusion results represented a decrease in hardness values of resultant ice cream, while, during storage, there was a slight increase. Energy input values decreased by increasing substitution levels of whey proteins. During storage, there was a low significant increase of energy input values. The energy output negatively correlated with substitution levels of whey proteins and positively with storage period indicating a strong structure for stored ice cream. Load at target deformation (50%) applied to the samples showing decreased values proportional to increasing substitution levels of whey proteins in ice cream samples when fresh and after 14 days storage. The resilience showed decreased ratio indicating more visco-elastic properties in fresh ice cream. The recovered height and deformation increased with increasing substitution levels of whey proteins and storage period. Therefore, more sticking properties were obtained in resultant ice cream. Adhesive force decreased significantly with increasing substitution levels of whey proteins and storage period. Adhesiveness values were significantly higher in all treatments than control and increased gradually during storage.

Key words: whey protein concentrate, whey protein isolate, glycomacropeptide, rheological properties, Ice cream, texture profile analysis, Back extrusion.

ACKNOWLEDGEMENT

Deepest, greatest and sincere thanks to **ALLAH** the most Merciful, Great and Clement God.

I gratefully wish to express my deepest gratitude and infinite thanks to my supervisor **Prof. Dr. Hoda Mahmoud El-Zeini** Professor of Dairy Science, faculty of agriculture, Cairo University. I would like to thank her for her great supervision, highly kindness, guidance as well as help writing of the manuscript of this work and her effort in statistical analysis and help in the rheological measurement, which exceptionally inspired and enriched my growth as a researcher.

I would like to express my second thanks to **Prof. Dr. Monier Mahmoud Ibrahim El-Abd** Professor of Dairy science, Faculty of Agriculture, Cairo University, for his supervision, and guidance through the course of study which give the work great value.

My deep appreciation for **Prof. Dr. Abdel-Rahman Abdel-Atti Ali**, Professor of Dairy science, Faculty of Agriculture, Cairo University, for his help in writing the manuscript and guidance throughout the course of study.

I would like also to express my gratitude and appreciation to **Prof. Dr. Moustafa Abd El-Moneam Zedan** professor of Dairy science, Food Technology Institute, Agricultural Research Center, Ministry of Agriculture, for his help offering facilities to accomplish lab. work,

Sincere thanks goes to **Dr. Rezk Azab Awad** Professors of Dairy Science, Faculty of Agriculture, Ain Shams University, for his help at the early stage of the lab work and continuous assistance throughout the investigation. He taught me several things which I never have the opportunity to learn. It is too difficult for me to express my deep respect to him.

Thanks also to everybody who provided, help or advice to achieve this manuscript.

LIST OF ABBREVIATIONS

"	Inch
%	percent
&	And
<	Less than
±	Plus or minus
®	Trademark
AOAC	Association of Official Analytical Chemists
C	Celsius
CMC	Carboxymethyl Cellulose
Co.	Company
CSS	Corn Syrup Solids
CV	Coefficient of Variation
DE	Dextrose Equivalent
DF	Degree of freedom
e.g.	For example
FAO	Food and Agriculture Organization
Fig.	Figure
FP	Freezing point
g	gram
gal	(1 U.S. gallon = 3.785 litre, 1 U.K. gallon=4.546 litre)
HTST	High temperature short time
J	Joule
K	Consistency index
kDa	Kilo Dalton
kg	Kilogram
lbf	Pound force; (1lbf = 4.448N = 0.4536 kgf)
LSD	Least significant differences
mEq	Millie equivalent
min	Minute
mJ	Milli joule
ml	Milliliter
mm	Millimeter
MPC	Milk protein concentrate
MS	Mean Square
MSNF	Milk solid not fat
MW	Molecular weight
n	Shear rate index
N	Newton; (1 N = 0.225 lbf)

Na ⁺	Sodium cation
nm	Nano meter
°	Degree
P	page
p.p.m	Part per million
PI	Protein isolate
pI	Isoelectric point
Prob.	Probability
qt	Quart
r	Regression coefficient
r.p.m	Round per minute
R ²	Multiple R
sec.	Second
Sp.gr	Specific gravity
TA	Titratable acidity
TC	Total calcium
temp.	Temperature
T _f	Freezing point temperature
TP	Total protein
TPA	Texture Profile Analysis
TS	Total solids
UF	Ultra filtration
UV	Ultra violet
v	volume
wk	week
WPC	Whey protein concentrate
WPI	Whey protein isolate
wt/wt	Weight by weight
α	Alpha
β	Beta
γ	(Gamma) Shear rate
η _a	(Eta) apparent viscosity
κ-casein	Kapa casein
μg	Microgram
σ	Shear stress

CONTENTS

	Page
1 INTRODUCTION	1
REVIEW OF LITERATURE.....	9
Characteristics of ice cream containing whey proteins	9
1. Ice cream and frozen dessert background and definitions	9
a. Sherbet.....	9
b. Frozen yogurt.....	10
c. Quiescently frozen dairy confections.....	10
d. Mellorine.....	10
e. Reduced fat.....	10
f. Light or Lite.....	10
g. Low fat ice cream.....	10
h. Nonfat ice creams.....	11
2. Ice cream composition	14
3. Ice cream ingredients.....	15
a. Stabilizers.....	18
b. Emulsifiers.....	23
c. Sweetners.....	27
d. Proteins	28
(1) Sources of bioactive milk proteins.....	29
(2) Characteristics of whey proteins in food products	32
(3) Structure and biological functions of whey proteins.....	33
(4) Composition and biological functions of whey proteins.....	35
(5) Whey proteins as essential food ingredients	36
(a) Structures of whey proteins	38
(b) Types and composition of whey protein based products	39
(c) Whey protein concentrate (WPC)	40
(d) Whey protein isolate (WPI)	43
(e) Milk protein concentrate (MPC)	44

(f Glycomacropeptide (GMP)	46
(g Whey protein hydrolysate (WPH)	49
(6 Functionality of WP and health benefits (whey-an emerging protein for improving body composition)	49
(7) Whey: biochemically tailored to preserve muscle	51
(ε Whey and satiety	55
(ϑ Why whey protein?	55
(a) Aging	56
(f Weight loss	57
(c Bone health	58
(c Good source of biologically active proteins and peptides	59
(ε Whey and cardiovascular health	60
(f Maturation	61
(c Functional properties of whey proteins and whey protein based products	62
(10 The application of whey proteins and whey protein products in frozen desert	64
4. Ice cream	65
a. Regulatory limitations	67
b. A range of functional ingredients	67
5. Functional benefits of whey in ice cream	68
a. Water Binding	68
b. Whipping/Foaming	68
c. Emulsification	69
d. Flavor	69
e. Viscosity	70
f. Visual appeal	70
g. Bulking agent	70
h. Freezing point management	71
i. Impact on added flavors	71
j. Cost-Effectiveness	71
k. Nutrition	72
6. Rheological properties of ice cream	72
a. Rheological and textural properties measurements	73

b. Empirical methods	74
MATERIALS AND METHODS	76
1. MATERIALS	76
a. Fresh skim milk and concentrated cream	76
b. Skim milk powder (SMP)	76
c. Whey protein concentrate (WPC), Whey protein isolate (WPI) and Glycomacropeptide (GMP)	76
d. Sugar	77
e. Stabilizer	78
2. METHODS	78
a. Method of ice cream preparation	78
3. Chemical analyses of ice cream mixes	80
a. Titratable acidity	80
b. Total solids.....	80
c. Ash content	80
d. Lactose content	81
e. Fat content	81
f. Total protein content	81
4. Physicochemical analyses of ice cream mixes	82
a. pH values	82
b. Specific gravity	82
c. Weight per gallon	82
d. Freezing point	82
e. Melting resistance of resultant ice cream	83
f. Calculation of the overrun	83
5. Rheological properties of ice cream	84
a. Ice cream mix	84
(1) Measurement of consistency	84
(2) Viscosity	84
b. Ice cream	85
(1) Texture profile analysis (TPA)	85
(2) Back Extrusion	86

6. Sensory evaluation	88
7. Statistical analysis	88
RESULTS AND DISCUSSION.....	89
SECTION I	89
1. Manufacture of ice cream containing	89
2. Properties of ice cream mixes	89
Chemical composition of ice cream mixes	89
(1) Total solid content	89
(2) Fat content	90
(3) Total protein	90
(4) Ash content	91
(5) Lactose content	92
b. Physiochemical properties	93
(1) Titratable acidity and pH values	93
(2) Specific gravity and weight/gallon.....	94
(3) Freezing point (°C)	95
(4) Consistency	96
(5) Apparent viscosity	97
c. Rheological properties	99
(1) Flow behavior Model	99
(2) Yield stress values	100
(3) Herschel-Bulkley equation	102
(4) Apparent viscosity	104
3.Properties of the resultant ice cream	106
a. Physical properties of ice cream	106
(1) Specific gravity	107
(2) Overrun	108
(3) Melting resistance	110
b. Texture profile analysis (TPA)	113
(1) Hardness	113
(2) Adhesiveness	114
(3) Cohesiveness	115

(4) Hesion	117
(5) Springiness	117
(6) Gumminess	119
(7) Chewiness	121
c. Back extrusion	121
(1) Hardness	123
(2) Position of hardness.....	123
(3) Energy input and output.....	125
(4) The load at target	127
(5) Resilience	127
(6) Recovered height	127
(7) Stringiness	128
(8) Best Fit	128
(9) Modulus slop	130
(10) Adhesive force	130
(11) Adhesiveness	132
(12) Start of adhesiveness	133
(13) Displacement at adhesive force	133
(14) End of adhesiveness	135
(15) Mm to break adhesive contact	135
4. Sensory evaluation	137
SECTION II	142
1. Manufacture of ice cream containing WPI	142
2 Properties of ice cream mixes	142
a. Chemical composition of ice cream mixes	142
(1) Total solid content	142
(2) Fat content	143
(3) Total protein	143
(4) Ash content	144
(5) Lactose content	145
b. Physiochemical properties	146
(1) Titratable acidity and pH values	146

(2) Specific gravity and weight/gallon.....	147
(3) Freezing point (°C)	148
(4) Consistency	149
(5) Apparent viscosity	150
c. Rheological properties	152
(1) Flow behavior Model	152
(2) Yield stress values	153
(3) Herschel-Bulkley equation	156
(4) Apparent viscosity	158
3. Properties of the resultant ice cream.....	160
a. Physical properties of ice cream	160
(1) Specific gravity	161
(2) Overrun	162
(3) Melting resistance	163
b. Texture profile analysis (TPA)	166
(1) Hardness	167
(2) Adhesiveness	168
(3) Cohesiveness	169
(4) Hesion	170
(5) Springiness	171
(6) Gumminess	173
(7) Chewiness	174
c. Back extrusion	175
(1) Hardness	176
(2) Position of hardness.....	177
(3) Energy input and output.....	179
(4) The load at target	180
(5) Resilience	182
(6) Recovered height	182
(7) Stringiness	183
(8) Best Fit	183
(9) Modulus slop	185

(10) Adhesive force	185
(11) Adhesiveness	186
(12) Start of adhesiveness	187
(13) Displacement at adhesive force	187
(14) End of adhesiveness	189
(15) Mm to break adhesive contact	189
4. Sensory evaluation	190
SECTION III	196
1.Manufacture of ice cream containing GMP	196
2 Properties of ice cream mixes	196
a. Chemical composition of ice cream mixes	196
(1) Total solid content	196
(2) Fat content	197
(3) Total protein	197
(4) Ash content	198
(5) Lactose content	198
b. Physiochemical properties	199
(1) Titratable acidity and pH values	199
(2) Specific gravity and weight/gallon.....	200
(3) Freezing point (°C)	201
(4) Consistency	202
(5) Apparent viscosity	203
c. Rheological properties	205
(1) Flow behavior Model	205
(2) Yield stress values	206
(3) Herschel-Bulkley equation	208
(4) Apparent viscosity	210
3. Properties of the resultant ice cream	212
a. Physical properties of ice cream	212
(1) Specific gravity	212
(2) Overrun	214
(3) Melting resistance	215