WHEAT ANTIOXIDANTS
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CONTENTS

Contributors xi

CHAPTER 1  OVERVIEW AND PROSPECTIVE 1
1.1 Introduction 1
1.2 Antioxidant Properties of Wheat Grain 2
1.3 Other Biological Activities of Wheat Antioxidants 3
1.4 Wheat Antioxidants: Opportunities and Challenges 5

CHAPTER 2  ANTIOXIDANT PROPERTIES OF WHEAT GRAIN AND ITS FRACTIONS 7
2.1 Sample Preparation 8
2.2 Total Phenolic Content (TPC) and Total Antioxidant Capacity (TAC) of Wheat Fractions 8
2.3 Iron(II)-Chelating Activity of Wheat Fractions 11
2.4 Oxygen Radical Absorbance Capacity (ORAC) of Wheat Fractions 13
2.5 Inhibition of Photochemiluminescence (PCL) by Wheat Fractions 14
2.6 Effect of Milling and Pearling of Wheat on Inhibition of Low-Density Lipoprotein (LDL) Oxidation 17
2.7 Influence of Milling and Pearling on Homediated Supercoiled DNA Scission by Wheat 19
2.8 Conclusions 20

CHAPTER 3  EFFECTS OF GENOTYPE, ENVIRONMENT AND GENOTYPE × ENVIRONMENT INTERACTION ON THE ANTIOXIDANT PROPERTIES OF WHEAT 24
3.1 Introduction 24
3.2 Genotype Effects 26
  3.2.1 Total Phenolic Content 27
  3.2.2 Phenolic Acid Composition 28
  3.2.3 DPPH Scavenging Capacity 31
  3.2.4 Superoxide Scavenging Capacities 31
  3.2.5 Peroxyl Radical Scavenging Capacities 32
3.3 Environment Effects 32
3.4 Genotype by Environment Interaction Effects 33
3.5 Relative Contribution of G, E, and G × E Effects to Total Variation 35
3.6 Concluding Remarks 37

CHAPTER 4  CAROTENOID, TOCOPHEROL, LIGNAN, FLAVONOID, AND PHYTOSTEROL COMPOSITIONS OF WHEAT GRAIN AND ITS FRACTIONS 42
4.1 Introduction 42
CHAPTER 8  EFFECTS OF EXTRACTION METHOD AND CONDITIONS ON WHEAT ANTIOXIDANT ACTIVITY ESTIMATION

8.1 Introduction 100
8.2 Extraction Methods and Conditions 101
  8.2.1 Effects of Extraction Method 105
  8.2.2 Effects of Extraction Conditions 106
8.3 General Considerations for Sample Preparation and Extraction 113
8.4 Extraction Condition Recommendations for Wheat Antioxidant Property Estimation 114

CHAPTER 9  METHODS FOR ANTIOXIDANT CAPACITY ESTIMATION OF WHEAT AND WHEAT-BASED FOOD PRODUCTS

9.1 Introduction 118
9.2 DPPH Radical Scavenging Capacity Assay 120
  9.2.1 Principles and Background 120
  9.2.2 Materials and Solutions Preparation 121
  9.2.3 Discussion 124
9.3 ABTS Cation Radical (ABTS\(^{**}\)) Scavenging Capacity Assay 125
  9.3.1 Principles and Background 125
  9.3.2 Materials and Solutions Preparation 126
  9.3.3 Measuring Procedure 127
  9.3.4 Calculations 127
  9.3.5 Discussion 128
9.4 Superoxide Anion Radical (O\(_2^{*-}\)) Scavenging Capacity Assay 130
  9.4.1 Principles and Background 130
  9.4.2 Materials and Solutions Preparation 131
  9.4.3 Procedure 131
  9.4.4 Calculations 131
  9.4.5 Discussion 132
9.5 Oxygen Radical Absorbing Capacity (ORAC) Assay 133
  9.5.1 Principles and Background 133
  9.5.2 Materials and Solutions Preparation 134
  9.5.3 Calculations 135
  9.5.4 Discussion 136
9.6 Hydroxyl Radical (\(^{\cdot}\)OH) Scavenging Capacity (HOSC) Assay for Hydrophilic Antioxidants 138
  9.6.1 Principles and Background 138
  9.6.2 Materials and Solutions Preparation 139
  9.6.3 Calculations 140
  9.6.4 Discussion 141
  9.6.5 Other Reported Methods for Hydroxyl Radical Scavenging Capacity Estimation 142
9.7 Hydroxyl Radical Scavenging Capacity Assay for Lipophilic Antioxidants Using ESR 143
  9.7.1 Principles and Background 143
  9.7.2 Materials and Solutions Preparation 144
  9.7.3 Procedure 144
CHAPTER 12 QUANTIFICATION OF PHENOLIC ACIDS IN WHEAT AND WHEAT-BASED PRODUCTS

12.1 Introduction 208
12.2 Background 209
12.3 Chemicals and Equipments 209
12.4 Methods 210
  12.4.1 Sample Preparation 1 210
  12.4.2 Sample Preparation 2 According to the Protocol Reported by Kim et al. (Fig. 12.2) 211
  12.4.3 HPLC Separation and Determination 213
12.5 Discussion 213

CHAPTER 13 EFFECTS OF WHEAT ON NORMAL INTESTINE

13.1 Introduction 219
13.2 Wheat Component Effects on Normal Intestinal Epithelial Cells in vitro 220
  13.2.1 Background Information 220
  13.2.2 Effects of Wheat Bran Extract on IEC-6 Cell Proliferation 222
  13.2.3 Ferulic Acid and IEC-6 Cell Proliferation 224
13.3 Discussion 232
13.4 Conclusion 234

CHAPTER 14 WHEAT ANTIOXIDANTS AND CHOLESTEROL METABOLISM

14.1 Introduction 236
14.2 Wheat Antioxidants 236
  14.2.1 Phenolic Acids 237
  14.2.2 Carotenoids 237
  14.2.3 Tocopherols 237
14.3 Wheat Antioxidant Properties 238
14.4 Cholesterol Homeostasis 239
14.5 Effects of Wheat Antioxidants on Cholesterol Metabolism 240
14.6 Summary 241

CHAPTER 15 WHEAT ANTIOXIDANT BIOAVAILABILITY

15.1 Introduction 244
15.2 Absorption Characteristics of Fluorescein In Vitro 245
15.3 Absorption Characteristics of Phenolic Acid In Vitro 247
  15.3.1 FA and PCA 247
  15.3.2 CA, CLA, GA, and RA 248
  15.3.3 Artepillin C (AC) 249
15.4 Absorption Efficiency and Bioavailability of Phenolic Acid in Rats 251
15.5 Absorption Characteristics of Colonic Metabolites of Poorly Absorbed Polyphenols In Vitro 253
15.6 Current Knowledge and Status of the MCT-Mediated Transport System 256
  15.6.1 Gastric Absorption 256
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1.1 INTRODUCTION

The pathology of a number of chronic diseases including cancer involves oxidative damage to cellular components. For instance, reactive oxygen species (ROS) capable of causing damage to DNA have been associated with carcinogenesis, coronary heart disease, and many other health problems related to advancing age. Minimizing oxidative damage may well be one of the most important approaches to the primary prevention of these aging associated diseases and health problems. Antioxidants terminate ROS attacks and appear to be of primary importance in the prevention of these diseases and health problems. It has been widely accepted that diet can significantly alter the overall health and quality of life. Development of functional foods rich in bioavailable antioxidants may play an important role in this regard. The key for developing functional foods is to provide a sufficient amount of the bioavailable safe active components, the functional additives/nutraceuticals, in the finished functional food products. Multidisciplinary approaches are required to select suitable agricultural materials containing adequate concentrations of beneficial components, to enhance and preserve the bioactives through postharvest treatments and optimized storage conditions, to understand their bioavailability and efficacy, to evaluate the potential side effects of elevated intakes of these bioactive components, to preserve the bioactive components during food formulation and processing, to evaluate the potential impact of the functional food intake on biomarkers of targeted health problems, and to promote the production and the consumption of these foods.

Recent research demonstrates that wheat grain contains significant level of natural antioxidants. Wheat is an important agricultural commodity and a primary food ingredient worldwide and contains considerable beneficial nutritional components. Wheat and wheat-based food ingredients rich in natural antioxidants can ideally serve as the basis for development of functional foods designed to improve the health of millions of consumers. Development of functional foods using wheat-based ingredients may also find value-added alternative utilization of wheat grain and fractions, thus enhancing agricultural economy.
1.2 ANTIOXIDANT PROPERTIES OF WHEAT GRAIN

Growing evidence indicates that intake of whole wheat foods may be associated with potential health benefits including the reduced risk of coronary heart diseases and certain types of cancer (1–3). These beneficial effects are attributed to the bioactive factors in wheat grain such as nondigestible carbohydrates and phytochemicals (1–4). Antioxidants are a group of small molecular weight phytochemicals present in wheat grain. These include but are not limited to carotenoids, tocopherols, lignans, and phenolic acids. These antioxidative components may prevent life important molecules such as DNA and enzymes from oxidative damages through different mechanisms. For instance, wheat antioxidants may directly react with reactive oxygen species (ROS) such as hydroxyl radicals or singlet oxygen molecules to terminate their attacks to biological molecules. Wheat antioxidants may also form chelating complexes with transition metals to reduce their availability as catalysts for free radical generation. Antioxidant properties of wheat grain and fractions and their phytochemical composition have been investigated and are summarized in Chapters 2–4. In addition to showing the significant level of natural antioxidants in wheat grain, the results from these studies suggest that antioxidants are not evenly distributed in wheat grain but are concentrated in wheat bran and aleurone fraction of bran. This finding may lead to the production and consumption of “super bran” and other wheat-based food ingredients rich in natural wheat antioxidants. The effects of genotype, growing conditions, and interaction between genotype and environmental conditions on antioxidant properties of wheat grain and fractions have also been reported by several research groups and discussed in Chapter 3. The results from these studies indicate the potential for producing wheat grain rich in natural antioxidants and other bioactive factors. These results also warrant further investigations for enhancing levels of natural antioxidants and other beneficial factors in wheat grain through wheat breeding effort, improved agricultural practices, and genetic modification.

Several research groups reported that wheat phenolic acids, a group of phenolic antioxidants in wheat grain, are predominantly present in the insoluble bound forms in wheat grain, along with a small portion in the soluble free or conjugated forms (Chapter 3), suggesting the possibility to enhance the availability of wheat antioxidant availability through improved postharvest treatments. A few studies investigated the postharvest treatments, milling practice, and storage conditions for their potential influences on the antioxidant availability in wheat bran. The results from these studies showed that postharvest enzymatic and yeast treatments, bran particle size, and storage conditions may significantly alter the antioxidant availability in wheat-based food ingredients (Chapter 6). Additional research is needed to advance our understanding of these postharvest and ingredient storage approaches and optimizing these conditions to enhance the antioxidant availability in wheat-based food ingredients.

Interestingly, recent studies showed the potential effects of food processing conditions on antioxidant availability in wheat-based food products and the antioxidant properties of selected food products (Chapters 6 and 7). It is well accepted that bioavailability is required for any bioactive food factors to have any health beneficial effects. Bioavailability depends on a number of factors including their availability in
food products, and their absorption and *in vivo* delivery to target organs and tissues. The availability of bioactives in food products is determined by their concentration in food ingredients and their preservation through food formulation and processing conditions. Interaction of wheat antioxidants with other food ingredients and the effects of food processing conditions such as thermal treatment on overall antioxidant properties of wheat-based food products are not fully understood.

Wheat phenolics including the phenolic acids and lignans are known antioxidants. Phenolic acid composition and lignan contents in different varieties of wheat have been studied (Chapters 3, 4, and 16). The interaction between the selected wheat phenolic acids and free radicals and transition metals was also investigated (Chapter 5). The bioavailability of phenolic acids from a few previous studies has also been discussed in Chapter 15. It is noted that food matrix may alter the availability and bioavailability of bioactives. Thoroughly designed animal and pilot human studies are needed to investigate the bioavailability of wheat antioxidants including phenolic acids and lignans from different wheat-based food ingredients and food products. This information is very important to optimize human benefits of wheat-based functional foods in natural antioxidants.

A number of analytical methods have been adapted and developed for investigating the antioxidant properties of wheat grain and fractions and their phytochemical compositions. These methods are summarized in details (Chapters 8–12). The limitations of these methods are also discussed along with their advantages and disadvantages. In addition to the spectrophotometric and fluorometric methods, electron spin resonance (ESR) spectroscopy has been discussed because it directly measures the presence of free radicals and has been utilized to evaluate radical scavenging activities of wheat antioxidants and to validate the analytical methods for wheat antioxidant research (Chapter 10). These analytical methods may be applied to other cereal grains and botanicals. It needs to be pointed out that there is still a need to develop new analytical methods that may evaluate antioxidant properties of a selected sample under physiologically relevant conditions and may compare hydrophilic and lipophilic antioxidants under same experimental conditions.

### 1.3 OTHER BIOLOGICAL ACTIVITIES OF WHEAT ANTIOXIDANTS

It is noted that wheat antioxidants may differ greatly in their chemical structures. Lutein, *α*-tocopherol, secoisolariciresinol, and vanillic and ferulic acids are known antioxidative compounds present in wheat grain (Fig. 1.1). They share a conjugation system with or without phenolic substitution(s). This common structural component allows them to have strong interaction with free radicals and convert the radicals to less reactive components, showing radical scavenging capacities. Besides their capacity to interact with ROS, wheat antioxidants may have other biological activities. It is well known that *α*-tocopherol has vitamin E activity, whereas lutein is a carotenoid compound that may affect macular pigment optical density (5). On the contrary, secoisolariciresinol is known as a phytoestrogen that may have potential in
chemoprevention of breast and prostate cancers, osteoporosis, and cardiovascular
diseases (6,7). In addition, ferulic acid, the predominant phenolic acid in wheat grain
or bran, has been shown to restore endothelial function in aortas of spontaneously
hypertensive rats and to prevent trimethyltin-induced cognitive dysfunction in mice
(8,9). In summary, individual antioxidant components may contribute to different

Figure 1.1 Chemical structures of the phenolic acids.
health beneficial effects of whole wheat foods or wheat antioxidants because of their different chemical structures.

A recent study showed that wheat antioxidants may alter mRNA levels of 3-hydroxy-3-methylglutaryl-CoA reductase (HMG-CoA-R) and cholesterol 7α-hydroxylase (CYP7A1). These activities are also not related or mediated through their antioxidative actions. Wheat antioxidants may alter total plasma and low density lipoprotein (LDL) cholesterol levels through altering the levels of these two enzymes. Effects of wheat antioxidants on genes involved in cholesterol metabolism are discussed in Chapter 14. Chapter 15 in this book discusses the potential effect of wheat antioxidants on normal intestinal cells and nutrient absorption. These biological activities may also contribute to their overall health beneficial effects. Additional research is needed to investigate the other biological activities of individual wheat antioxidant compounds \textit{in vitro} and \textit{in vivo}, potential synergistic effects between wheat antioxidative components, the molecular mechanisms involved in their bioactivities, and their possible toxic effects.

1.4 WHEAT ANTIOXIDANTS: OPPORTUNITIES AND CHALLENGES

Wheat is an important agricultural commodity and a popular food ingredient worldwide. Wheat antioxidants and other beneficial phytochemicals are concentrated in the bran fraction of wheat grain. Bran is mostly used for low-value animal feed instead of human food ingredient. Research promoting the production and consumption of wheat-based food ingredients and food products rich in natural antioxidants may provide new value-adding opportunities for wheat bran, whole wheat flour, and other wheat-based food ingredients, which may benefit wheat growers, grain processing industry, food ingredient industry, and food manufacturers. The consumer desire of health beneficial functional foods also promotes research in the fields of wheat breeding, plant physiology, general plant science, food chemistry, food processing, general food science, nutrition, human health, and other biological and health sciences.

Wheat antioxidants also offer challenges for researchers in the related fields. Multidisciplinary approaches are required to advance our knowledge on wheat antioxidants. For instance, chemists and crop scientists have to work together to investigate how agricultural practices may alter antioxidant property and composition of wheat grains. It is also hard to ensure the consistency of wheat antioxidant properties in wheat grain and wheat-based food ingredients because many factors may be involved. To date, the chemical composition of wheat antioxidants is not fully understood. This makes it hard to quantify individual antioxidant compounds in the wheat-based food ingredients, which may be important for quality assurance of wheat-based food ingredients rich in antioxidants.

Food is a very complicated chemical system. Many interactions between food components may occur during food formulation, processing, and storage. These interactions may alter the status of individual antioxidants in the system, which may
alter the effectiveness of analytical approaches such as antioxidant extraction. This makes it very challenging to research chemical components in food.

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There is a growing interest in phytonutrients or plant-derived bioactives that occur naturally in foods and possess curative and preventive properties above their nutritional value (1). In general, fruits and vegetables have been shown to contain compounds that contribute to human health (2). However, little attention has been paid to cereals with respect to their contribution in human health promotion and disease risk reduction, despite the fact that they serve as staple foods for most of the world’s population (3). Among different cereals, wheat is the most important one in the temperate climate (3). There are two commercially important wheat types, namely, durum wheat or pasta wheat and common or bread wheat (4).

Antioxidant activity is an important biological property of many phytochemicals that protects living organisms from oxidative damage thereby preventing various deleterious events and diseases in plants and animals including human beings (5). Phenolic compounds possess antioxidant activity and these are aromatic secondary metabolites of phenylalanine, and, to a lesser extent, tyrosine that constitute one of the most diverse family of compounds found in plants (6). Simple phenols, phenylpropanoids, flavonoids, tannins (proanthocyanidins and others), and lignins are among numerous categories of plant phenolics (7). Cereals have been known to contain phenolic acids, phytoestrogens, and small quantities of flavonoids (8). The phenolic acids in cereals are benzoic and cinnamic acid derivatives; the latter being most common (9). Cereals are also a major source of dietary lignans with potent antioxidant activity (10).

In cereal grains, phenolic acids are concentrated in the cell walls of their outer layers mainly esterified to the arabinose side groups of arabinoxylans (11). On the contrary, Goupy et al. (12) have reported that phenolic acids are mainly found in the aleurone layer and endosperm of cereals. In general, ferulic acid is the major phenolic acid in many cereals that exists predominantly in the seed coat (13), while traces of ferulic acid may also be found in the starchy endosperm (14). Sosulski et al. (15) reported the presence in wheat of \( \text{trans} \)-ferulic, syringic, and vanillic acids, while
Hatcher and Kruger (16) reported six phenolic acids, namely, sinapic, ferulic, vanillic, syringic, caffeic, and coumaric acids. Oat and corn also contain several different phenolic compounds including $p$-hydroxybenzoic, vanillic, protocatechuic, syringic, ferulic, caffeic, and synapic acids (15). Presence of $trans$-ferulic, syringic, $p$-hydroxybenzoic, and protocatechuic acids was reported in rice (15). In addition, oat ($Avena sativa$ L.) has been considered as a good source of antioxidants. According to Gary et al. (17) oat contains a range of functional ingredients that are concentrated in different parts of the kernel. The main antioxidative constituents of oat include vitamin E (tocols), phytic acid, phenolic compounds, and avenantheramides; flavonoids and sterols are also present to a lesser extent. These antioxidative constituents are concentrated in the outer layers of the oat kernel (18). According to Terao et al. (19) ferulic acid is the dominant phenolic acid in rye, wheat, and barley.

The health benefits of cereal grains may possibly be attributed to the nature of their cell wall polymers and chemical architecture (20,21). Phenolic acids, which are covalently bound to the insoluble wheat bran matrix, have been shown to possess different antioxidative functions (22). Recently, phenolic acids have gained attention because of their antioxidative, antiinflammatory, antimutagenic, and anticarcinogenic properties as well as their ability to modulate some key enzymatic functions in the cell (23). However, little detailed or systematic information is known about distribution of phenolics in wheat grain. Thus, the work reported here was carried out to fill an important gap in the existing knowledge in the field and to shed light on phenolics of wheat and their potential health benefits.

### 2.1 SAMPLE PREPARATION

Grains were obtained from the Canadian Grain Commission (Winnipeg, MN) and processed by milling and pearling. The milling yielded bran, flour, shorts, and feed flour. During pearling, the bran layers were sequentially removed from wheat kernels by abrasion. Starting from unprocessed grain, kernels were pearled from 10% to 50% in 10% increments, and the pearled wheat and corresponding by-products were collected separately at each level. The crude phenolic compounds present in wheat milling fractions, pearled grains, and their byproducts were extracted into 80% aqueous ethanol ($1:10$, w/v) at $4^\circ C$ for 16 h.

### 2.2 TOTAL PHENOLIC CONTENT (TPC) AND TOTAL ANTIOXIDANT CAPACITY (TAC) OF WHEAT FRACTIONS

Wheat class CWRS (Canada Western Red Spring; $Triticum aestivum$ L., crop year 2001) includes common bread wheat, while CWAD (Canada Western Amber Durum; $Triticum turgidum$ L. var. durum, crop year 2002) wheat class is mainly grown for production of semolina (coarse flour prepared from durum wheat). TPC and TAC of milling and pearling fractions of wheat classes CWAD and CWRS are shown in Figs. 2.1 and 2.2, respectively. The content of total phenolics was
determined according to a modified version of the procedure described by Singleton and Rossi (24), while TAC was determined according to the Trolox equivalent antioxidant capacity (TEAC) assay described by van den Berg et al. (25) with slight modifications. The TPC of milling fractions ranged from 140 to 2279 mg FAE/g defatted wheat and from 216 to 3437 mg FAE/g defatted wheat for CWAD and CWRS, respectively. The TAC expressed as μM Trolox equivalents (TE), was positively correlated with TPC of CWAD and CWRS. The TPC and TAC decreased in the order of bran > shorts > feed flour > whole grain > flour for both wheat classes. However, CWAD possessed an additional fraction, namely semolina, which is a product derived only from endosperm of durum wheat. Semolina possessed the lowest TPC and TAC among various fractions examined for CWAD. In both wheat classes, bran had significantly higher TPC and TAC compared to the endosperm that affords the flour (endosperm of wheat kernel) fraction. The higher TPC and TAC in shorts (a mixture of bran, endosperm, and germ) and feed flour (a mixture of bran and low grade endosperm) compared to flour can be explained by the presence of various proportions of bran (the outermost layers of the wheat kernel including aleurone layer) and germ (wheat embryo) in them. In the whole grain (unprocessed wheat grain), the endosperm dilutes the antioxidant substances present in the bran and

Figure 2.1  Total phenolic content (a) and total antioxidant capacity (b) of milling fractions of CWAD and CWRS wheat types. Abbreviations are WG, whole grain; B, bran; F, flour, SH, shorts; FF, feed flour; S, semolina; CWAD, Canadian Western Amber Durum; and CWRS, Canadian Western Red Spring.
hence TPC and TAC in the whole grain are lower compared to the bran fraction alone.

In another study performed to obtain bran-rich and starch-rich fractions of wheat using milling and sieving, a higher TPC and antioxidant activity in the bran-rich fraction was noticed when compared with those in the starch-rich fraction (17). Although whole grains are known to provide benefits to humans owing to their unique phytochemical composition, the antioxidant activity of pearled wheat fractions and their by-products has not been studied to any great extent. Figure 2.2 represents the TPC and TAC of pearled wheat grains and their by-products. The whole grains and the grains pearled to remove 10% of the external layers possessed the highest TPC and TAC. The TPC and TAC decreased in the processed grain as the degree of pearling was increased. For CWRS, TPC in the 10% pearled grains and by-product, respectively, was 2.5 and 4 times higher than that of pearled grains and by-products of 50% pearling level; the corresponding values for CWAD were 2.4 and 4.1 times. Moreover, TAC decreased from $3.1 \pm 0.04$ to $1.9 \pm 0.03$ and $4.5 \pm 0.04$ to $1.6 \pm 0.02$ µmol TE/g, respectively, for CWAD and CWRS from 10% to 50% pearling. Significantly higher values of TPC and TAC for CWRS compared to those of CWAD may be attributed to the existing differences in genetic composition of the two wheat classes that are comprised of different species. Despite this difference, whole grains of both wheat classes possessed higher TPC and TAC compared to their pearled wheat grains. The TPC and TAC decreased with each level of pearling and the 10% pearled grains had the highest values when compared to a higher pearling level. However, the by-products always had a greater TPC and TAC compared to the respective pearled grains. Pearled samples of both CWAD and CWRS wheat classes contained remnants of both bran and germ. When the degree of
pearling was increased, the existing phytochemicals were diluted as the pearled grains composed mainly of endosperm. At each level of pearling, phytochemical-rich external layers were removed leaving a greater proportion of endosperm in the pearled grain. However, the deep crease in the wheat grain did not yield uniform removal of the external layers. Hence, complete removal of external bran layers did not result in total removal of pericarp and aleurone from the crease of the pearled wheat grains. According to Dexter and Wood (26) the proportion of bran and germ in a whole grain is 14% and 1%, respectively. The by-product at 10% level of pearling predominantly includes bran layers, while at 20% level it contains a mixture of endosperm, aleurone, and bran. Zhou et al. (27) have shown that aleurone layer contributed significantly to the TPC and hence to antioxidant capacity of wheat. The same phenomenon can be attributed to the higher antioxidant capacity of by-products resulting from 20% pearling than those resulting from 30% to 50% pearling. Theoretically, beyond 20% of pearling, the by-product should be composed of endosperm alone; however, contamination always exists due to the residual crease in the pearled grain.

Phenolic compounds were concentrated in the bran fraction, while endosperm also possessed some that contributed to TAP and hence TAC (28,29). Fulcher (30) has reported that wheat phenolics are in general concentrated in cell walls of the aleurone layer. The 10% by-product fraction would be primarily pericarp with significant amounts of aleurone, while 20% fraction would be rich in aleurone. However, with the latter, the antioxidant levels are similar to 10% because of the presence of a higher amount of endosperm, which is poor in antioxidants. Martinez-Tome et al. (31) observed that oat and wheat bran were associated with high antioxidant activity. It has also been demonstrated that whole wheat and its milling fractions, especially bran, are rich sources of phenolic compounds (32–34). Peterson et al. (35) determined the antioxidant activity of oat by pearling them for 5 to 180 s. The authors observed higher antioxidant activity in the short-pearling fractions as longer pearling times removed most of the external layers leaving starchy endosperm in the pearled products. Moreover, Peterson (18) reported that antioxidative components were concentrated in the outer layers of the wheat kernel. Emmons et al. (36) have shown that extracts of oat pearling fractions possessed higher TPC and antioxidant activity than those prepared from the flour fractions. The study reported here also suggests that the degree of pearling should be kept at a minimum in order to retain the high-value bioactives in the pearled grains.

2.3 IRON(II)-CHELATING ACTIVITY OF WHEAT FRACTIONS

According to Kehrer (37), iron chelation may render important antioxidative effects by retarding metal-catalyzed oxidation. The effective iron chelators may afford protection against oxidative damage by removing iron(II) that may otherwise participate in hydroxyl radical-generating Fenton-type reactions. Minimizing iron(II) protects against oxidative damage by inhibiting production of reactive oxygen species (ROS) and lipid peroxidation. The iron(II)-chelating activity of various wheat milling
fractions and pearled wheat grains and by-products were determined by measuring the formation of iron–ferrozine complex. Figure 2.3 summarizes the results obtained for chelating effects of wheat fractions on iron(II). Among different milling fractions, bran demonstrated superior chelating properties over the other fractions examined. Flour and semolina demonstrated the lowest iron(II)-chelation capacity. The iron(II)-chelation capacity of pearled grains varied from $618 \pm 69$ to $682 \pm 35$ and $620 \pm 47$ to $723 \pm 42 \mu g$ EDTA (ethylendiaminetetraacetic acid) equiv/g of defatted wheat of CWAD and CWRS, respectively. The corresponding values for the by-products were from $692 \pm 21$ to $1173 \pm 59$ and $703 \pm 38$ to $1206 \pm 68 \mu g$ EDTA equiv/g, respectively. The whole grains always demonstrated higher chelation capacity compared to the pearled grains. Results indicated the presence of iron(II)-chelating agents such as

Figure 2.3  Iron(II)-chelation capacity (μg EDTA equiv/g) of milling fractions (a), pearled grains, and by-products of two wheat class, CWAD (b) and CWRS (c). Abbreviations are WG, whole grain; B, bran; F, flour, SH, shorts; FF, feed flour; S, semolina; P10, 10% pearling; P20, 20% pearling; P30, 30% pearling; P40, 40% pearling; P50, 50% pearling; CWAD, Canadian Western Amber Durum; and CWRS, Canadian Western Red Spring.
phenolics in association with bran layers and hence the by-products are examined. Metal-chelating properties have been reported for amino acids and short peptides that can be easily extracted into an aqueous medium (38). Shahidi (39) reported that constituents such as amino acids, peptides, and proteins might play a significant role as physiological and dietary antioxidants thereby augmenting the antioxidant properties against oxidative damage. The antiradical properties exhibited by wheat extracts were also directly proportional to their iron(II)-chelating properties. It has been reported that high iron status or iron overload is positively correlated with coronary heart disease risk (40). Hence, increased intake of phenolic compounds may maintain a relatively low iron status thereby reducing the risk of iron overload (41).

2.4 OXYGEN RADICAL ABSORBANCE CAPACITY (ORAC) OF WHEAT FRACTIONS

The antioxidant activity of wheat milling fractions, pearled grains, and their by-products measured by the ORAC assay, as determined according to the method of Dávalos et al. (42), showed effective scavenging of peroxyl radical especially by the products containing bran (Fig. 2.4). The ORAC values of wheat fractions were expressed as μmol TE/g of defatted wheat. The ORAC values of wheat milling fractions ranged from 45 ± 2 to 301 ± 5 and 54 ± 2 to 310 ± 3 μmol TE/g for CWAD and CWRS cultivars, respectively. The ORAC of milling fractions was in the order of bran > shorts > feed flour > whole grain > flour. A general agreement in the rank order with regard to ORAC was noted between CWAD and CWRS. Hence, bran possessed the highest ORAC, while flour and semolina fractions had the lowest ORAC. The ORAC values for samples of CWRS were much higher than those of CWAD that may be attributed to the varietal differences. The ORAC of wheat bran was approximately 6.8 folds higher than those of flour fractions for both CWAD and CWRS. The antioxidant activity of pearled wheat grains and their by-products showed effective scavenging of peroxyl radical, especially by the by-products at 10% to 20% pearling. According to Hendelman et al. (43), the ORAC of oat varied from 2.08 to 8.13 μmol/g. These authors found that the bran and flour had similar antioxidant activity due to the mixing of the bran with the starchy endosperm. However, the aleurone layer possessed the highest ORAC value. In contrast, this study demonstrated that the by-products at 10% and 20% pearling, containing mainly bran and aleurone portions, possessed a much higher ORAC value than all pearled grains and by-products at 30 to 50% pearling; wheat demonstrated better antioxidant activity than oat in the ORAC assay (43). However, ORAC was determined using two different methods in the two studies, and hence comparison becomes rather difficult. Thus, the antioxidant capacity of wheat can primarily be attributed to the constituents present in the bran layers. Zhou et al. (27) determined the antioxidant activity of bran and aleurone layers of a Swiss red wheat variety and found that the aleurone layer exerted 7 to 8 times more antioxidant activity than that of the bran layer as determined by the ORAC assay. Thus, consumption of whole grains may provide full advantage of all antioxidative compounds present in wheat.
2.5 INHIBITION OF PHOTOCHEMILUMINESCENCE (PCL) BY WHEAT FRACTIONS

The antioxidative potential of whole grains and milling fractions and of pearled wheat grains and their by-products as measured by PCL method is shown in Figs. 2.5 and 2.6. 

**Figure 2.4** Oxygen radical absorbance capacity (ORAC, μmol Trolox equiv/g) of milling fractions (a), pearled grains, and by-products of two wheat classes, CWAD (b) and CWRS (c). Abbreviations are WG, whole grain; B, bran; F, flour, SH, shorts; FF, feed flour; S, semolina; P10, 10% pearling; P20, 20% pearling; P30, 30% pearling; P40, 40% pearling; P50, 50% pearling; CWAD, Canadian Western Amber Durum; and CWRS, Canadian Western Red Spring.