Narrator: Walter Bushuk (WB)

Company Affiliations: University of Manitoba, Canadian Grain Commission—Grain Research Lab

Interview Date: 27 February 2009

Interviewer: Marion Campbell (MC)

Recorder: Nancy Perozzo (NP)

Transcriber: Rebecca Kirkpatrick

Summary: In his first interview, cereal chemist with the University of Manitoba Walter Bushuk discusses his career in grain research. He describes his first interaction with grain science as a graduate student in the Canadian Grain Commission's Grain Research Lab and choosing to focus on grain science for his career. He explains his major area of research into wheat proteins and their affect on flour quality and end-use products, and he explains the outcomes of high and low protein wheat in bread. He describes his early work on triticale, a varietal cross between durum and rye, and the results of that research. He discusses the practical uses of his research into grain protein, particularly for plant breeders and the development of rapid testing technology. Bushuk describes research into methods of improving grain quality, either through plant breeding or chemical modification, as well as research into improving baking and milling processes. Other topics discussed include research into grain rust disease, growing varieties of consumer breads, changes to varietal registration standards, and his work on digital image analysis for grain inspection and segregation.

Keywords: University of Manitoba; Canadian Grain Commission—Grain Research Lab; Grain research; Grain science; Cereal chemistry; Food science; Protein testing; Grain varieties; Plant breeding; Triticale; Plant cross-breeding; Grain diseases; Grain rust; Grain processing; Bread baking; Flour milling; Seed variety registration; Grain grades; Visual inspection; Digital image analysis

Time, Speaker, Narrative
MC: I am talking today with Dr. Walter Bushuk, in the reading room of the Food Science Building at the University of Manitoba on February 27, 2009, a Friday. I would like to start by saying, can I call you Walter on the tape? WB: Of course. MC: That's great then. You have had a long, long career working in the grain industry doing research and doing all sorts of wonderful work around the world and being an administrator in various settings. I am wondering if you could tell us a little bit of

how you got interested in grain industry to begin with, the research, and how you got interested in that kind of research? What sparked your interest in this application of your chemistry training to this particular field rather than other areas that you could potentially have applied that science to?

WB: Thank you very much, Marion. It is a pleasure to have the opportunity to participate in this what appears to be a very exciting project. I am honoured to be asked to make a contribution.

My interest in wheat began in the early 1950s when I was given a summer job at the Canadian Grain Commission laboratory, to work as a summer student research assistant, and what that began is an interest that has stayed with me all my professional career from two perspectives. It gave me an interest in wheat, which is an important agricultural product, and secondly it gave me an interest in an activity called research. What could be more interesting than having an opportunity to study mother nature and find out how it works in all aspects of human endeavour? So, it began with a summer job while I was a student at the University of Manitoba and stayed with me while into post retirement. I am still very much involved with things that I have been going on, and I will be talking about later.

MC: It is wonderful that you as we define work is really something that you can do for play as well as for work. That is a wonderful thing to have in your life! Not everybody has that. I am wondering if you could tell us a little bit about the type of work you have done over the years as a cereal chemist thinking about the application of science in the grain industry area. Could you tell us a bit about some of the kinds of work and projects and so on that you have done? There have been many.

WB: It's a story that is very interesting and very complex. The main objective of my research has been to determine the nature of quality that wheat has in relation to its processing into bread. What is it that is important in terms of chemistry, physics, biochemistry that is important for the ability of wheat, after it is converted into flour, to produce the product that we prefer, that we like, as we consume the product as part of our food menu?

MC: In terms of quality, the nature of quality, what have you focused on particular and what have you discovered in terms of quality aspects?

WB: Most of my research has focused on the protein component of wheat flour. Proteins form approximately 13 percent of flour. They are not the major component, but so far as the quality is concerned, proteins are the most important component of wheat flour. Now the proteins are unique to wheat. There are many different proteins in the plant world, in the animal world and their uniqueness is important to the way they behave in the processing of a product from one type to another. From wheat into flour, proteins play a role in the process.

What we try to do, and have had some success, is to characterize the proteins in terms of basic properties such as molecular size and molecular shape. These properties are unique, and they play a role in the way the product behaves during processing or the way the product contributes to the nutritional value. Two quality aspects that interact. One is the physical properties that determine how the product is processed. The hardness of grain for example will affect its conversion into flour. Protein content of flour will determine how the flour will behave when you add water to it and start mixing it into a dough, which is subsequently converted into bread. But the way the dough develops depends on not only the amount of protein but the type of protein. That is one aspect of the role of protein in the bread making process.

The other factor that comes into play is how the protein is inherited in new varieties, as new varieties are developed. We study different varieties in order to be able to characterize those varieties that have better quality for a product that we are tying to make. So, going back to your original question, yes, the quality of flour or wheat is determined by the basic molecular properties of the constituents of the flour or the wheat. Once we find out how the constituents play a role in the quality, we go back and determine how that particular constituent is inherited in new varieties so that we can tell the wheat breeder what varieties to select in his breeding process, so that the new variety is produced by crossing a number of old varieties will have the quality that is suitable for a particular product.

MC: When you are saying how proteins are inherited in new varieties, that word "inherited" are you meaning genetics? What do you mean by inherited?

WB: Yes, genetics would be a good explanation. Inherited in this case refers to the way in which constituents are inherited after crossing two varieties that are different. You select two varieties that have specific properties. Hopefully by crossing these varieties, the properties that give good quality will be inherited in the new variety.

Now it will take maybe as long as 10 to 12 years of crossing and selecting to get a variety that has the desirable characteristics. The characterization of new variety produced by crossing requires many different tests—chemical and physical tests. As chemists, we try to identify the tests that are most indicative of the quality that we are interested in. Then we develop rapid tests that we can provide for the breeder to test the many lines, many varieties, that are produced in the crossing process.

MC: When you are talking about the emphasis on protein in particular as the focus of your research, what would be some of the projects that you would have worked on? I know you have worked in triticale and some of the new varieties of wheat. Could you tell us a bit about some of the applications or particular grain products or things like that were the focus of your protein research?

WB: The focus has been mainly on the structure of different proteins. In wheat flour, the protein fraction is made up of several hundred different proteins, and these work together to give the complex system that we call a dough. Some of my research has been focused on identifying which proteins contribute to quality. Once we identify these proteins, we study the structure—the molecular structure—the size, shape, composition. We study this structure to determine which part of the structure the molecular weight, molecular size, the coiling of the proteins and so on. We determine which part of the structure plays a major role in the conversion of flour into bread. Once we identify, say for example, the protein "A", because of its molecular size plays an important role in the function of protein in bread making, we can develop tests to measure this property in the protein that is important to the property.

Then we can go to the breeder and say, protein X which has 100,000 molecular weight is the key protein, and therefore we will develop tests like, for example, electrophoresis, which we talk about quite a bit in this book. We develop tests that focus on that particular protein, and we tell the breeder give us your sample, and we will measure the amount of that particular protein and tell you whether it is good or not good for a particular product that we are investigating.

MC: The book you are talking about is called *Wheat Quality Elucidation: The Bushuk Legacy* edited by Perry K.W. Ng and Colin W. Wrigley. We can look at that to get more detail.

WB: There is another book that is somewhat more specific that we have published. I was a co-author of this book, and Colin Wrigley from Australia was a co-author and another colleague from Hungary. That book deals with specifically two proteins in wheat flour that are most important for bread-making quality. These proteins are called glutenin and gliadins. If someone wants to delve into the details of those two proteins and how they contribute to wheat flour quality that would be the book. It has just been published a year and a half ago.

MC: Did you give me the name of that book? Do you have the title of that book?

WB: I didn't give you the name, but the main part of the title is *Gliadis and Glutenin*. These are the two proteins. There is a sub-title to that.

MC: We can certainly get that name and that would be excellent.

WB: Yes. I have a copy, but I am sure there is a copy in Agriculture library. Much of my research over the last 30 years has focused on this particular protein.

MC: The two proteins?

WB: Yes, the two proteins and their nature, their molecular structure, their inheritance—genetics if you want to call it. Again, much of the information is what we call basic or fundamental. We hope that maybe at some time in the future the information will be useful. But some information is readily applicable to problems that we are trying to solve at the present time. Our research covers a full range from very fundamental. I prefer the word basic because basic carries a practical connotation. But there is an application for what we are trying to do.

MC: If we think about some of the early work that you did, would triticale be the first area where you investigated these issues related to protein quality?

WB: The first graduate student that I had when I came on staff in 1967, his PhD research project was in triticale. We had a very simple question: When you produce triticale by crossing durum wheat and rye, two alien species crossed to give a third species, there were conflicting reports in the literature that the crossing produces new components that are not present in either of the two parents. It is like blue eyes and brown eyes crossed to give you something that is not in either of the varieties. Actually, Marion Vaisey-Genser did some work and produced results that were in conflict of theory, and although no one had done the research to prove or disprove her hypothesis, we decided to do it. Albert Chen, my first PhD student, was assigned to test the hypothesis that new proteins are produced when you cross two different species like durum wheat and rye which are crossed to produce triticale.

We did the project, and we found that triticale does not have in it proteins that are not found in either of the two varieties. In other words, there are no new proteins. We published the papers and I think that put it to rest that idea. The way we explained the results that Marion obtained was that in the fractionation, in characterizing proteins, they are first extracted and purified to eliminate all the conflicting other constituents. When we carefully and completely separated the proteins in triticale, we found that all the proteins that are present in triticale are present in one or the other parent. So, there were no new proteins produced. It is very interesting. What this means in practice, that triticale is nothing more than a combination, physical combination, of the two parent varieties.

We also did some work on starch, but our main interest was the protein component. The conclusion was that if someone wants triticale, you can get the same result in the flour and in the bread from mixture of rye and durum wheat. Unless triticale has some unique properties, it wasn't very attractive for Canada to be producing triticale. In France by a modified crossing procedure, they have produced triticales with high protein content, 18 percent, compared with 12 percent for normal triticale. This high protein triticale is being used as a source of protein for animal feed—animals that require proteins as part of the feed mixture for hogs for example. It is being grown for that purpose. In Canada it is still a scientific curiosity, although I think you can purchase triticale in speciality stores and use it for special products—cookies and breads. There is some interest in it.

MC: Your reference to Marion Vaisey-Genser, she was a faculty member here at the university as well and I guess it was Home Economics at that time and currently Human Ecology. I would imagine this is just one of many collaborations in your research. Maybe you can tell us a bit of your work in this area of triticale and Marion's. She was a sensory scientist. Could you tell us a little about that collaboration or were there others involved in that triticale work? I imagine you were not making bread. Maybe Marion was making bread. Is that how all that worked together?

WB: They were done during different times. Marion's work was done earlier by maybe a period of five to eight years. When I came to the university and got my first graduate student to work on this, the plant breeders and the geneticists working on triticale Dr. Larter and his colleagues were questioning the results that had been published. This happens, not very often, but quite frequently and colleagues in the department of Plant Science where I was at the time, Dean Shebeski as well, challenged us, the chemists, to confirm the formation and presence of new proteins that was claimed were present in the triticale.

Another feature that had to be very carefully checked is to make sure that the control samples of triticale and the durum parent and the rye parent were exactly identical as those used to produce the triticale, as parents. Because there had been some publications, which were based on results obtained on triticale and rye, the rye component which as different, than that used to make the triticale. Of course, if that is the case it is quite likely that rye in the triticale component was different than the rye in the parent that was used to produce the triticale.

We had to plan our work carefully when we received samples of triticale and the two parents, durum wheat and rye. We had to check very carefully that the rye and triticale and the rye that was used as the parents were identical and the same. That required many tests like the one in this book, and even required growing these varieties out in the field to make sure that the growing cycle didn't produce some change within the triticale, to give a new protein. That was an interesting bit of work and I think we resolved the controversy that was in the literature.

MC: That result you were mentioning that your research showed there were no new proteins as a result of the cross. Is that result that you found with triticale, is that true for crossing other and was it specific to triticale or is that a general finding of crossing in others?

WB: Crossing and producing new varieties of wheat, for example, which involves the cross of two different varieties--.

MC: Are you saying this is a finding is general to crossing other triticale with durum and rye? For other crossing, no new proteins?

WB: Yes.

MC: So it was a generalized finding?

WB: Yes. Except if you produce a new variety by a technique like irradiation, you can create new proteins by actually changing the gene. But you do that not by physical crossing but by techniques, either chemical treatment or irradiation where you change the DNA template which in turn produces different proteins.

MC: I would think that at the state you were doing this research, we were not into these genetics and now it is totally different.

WB: Now they do it, for example, in India, they were able to change a red wheat into a white wheat by irradiation. This was a useful transformation for some areas where the preferences for white wheat. In that case there was a change in the composition of the protein component.

MC: You have mentioned several times about the desire to produce new varieties. Why are new varieties important? Other than to satisfy scientist and breeders to come up with new, strange, and wonderful products?

WB: New varieties are being produced mainly because the old varieties, after a number of years, become susceptible to diseases. The diseases will adapt to the molecular environment in a variety that is resistant to a specific disease and produces well under a set of conditions, gradually becomes susceptible. It is necessary for us to produce new varieties that will have disease resistance. Rust is one disease that is mutating all the time, and we have to keep a step ahead in order to have a crop that will produce proper seed.

MC: Your research in triticale probably like all research raises more questions than it answers and leads you in certain directions. Did that work lead you to apply some of this knowledge? What would be some of the next things you worked on?

WB: That first bit of research helped us develop techniques that could be used for quick measurement of the composition of proteins in wheat flour. We then were able to extend that work to develop technologies that could help us identify the parents of a new variety by comparing the electrophoretic patterns, the bands for particular proteins. We can determine, or identify, a variety as to its parents. That information is useful in practice for identifying if a wheat variety meets the regulations of being registered as an acceptable variety for our production.

MC: Would Glenlea wheat be one of the things where you applied some of this technology to this particular variety or other wheat varieties?

WB: Glenlea is a very interesting variety in that it doesn't meet our quality requirements because it is too good, too strong. I proposed that because of its high yielding potential, that we should develop Glenlea wheat by introducing a variety by crossing it with a variety that will make the protein a little weaker.

MC: When you are saying a protein is too strong and you said make it a little weaker, could you just tell us what you mean by that? I am not familiar with that terminology.

WB: The strength refers to the rheological the mixing properties of the flour or the variety into dough. Wheat flour mixed into a dough exhibits a property called viscoelasticity. It is both viscous, like honey—it will flow—but also it is elastic, like rubber, and the baking quality of wheat requires a balance between viscosity and elasticity, which are two fundamental properties of rheology. It has to have certain amount of viscosity so that you can mix it quickly and develop it properly. But it has to have elasticity, so that it can form the structure that is required to contain or maintain or retain the gas during fermentation and give the bubbles.

MC: All the little holes in our bread that we like, or some of use like.

WB: Yes. If it is too viscous then it won't expand. If it is not viscous enough, it will give a dough that is very tight, and bubbles will be fine and not the type that we prefer in our bread. Although in some countries, they prefer coarse breads. But that brings us into another basic scientific field called rheology, which is very important as far as baking performance of wheat-bread dough is concerned.

MC: I interrupted you when you were talking about your ideas about how to improve Glenlea wheat that is was too strong, and you wanted to oppose the idea of weakening this viscous wheat variety. That is where we left off before I interrupted you. Maybe you could go back now after we know what you mean by strong and weak how you propose to weaken that variety and where that took you?

WB: It didn't take me very far because my colleagues at the Grain Commission didn't think it was the direction to go. We had a variety was exactly what was wanted. We didn't want to produce another variety that would require a lesser amount than the varieties that we now grow. They did not wish to continue.

MC: To support that direction you were going?

WB: Yes, they felt it was a conflict of interest. Glenlea was licensed as extra strong for a while, but then it was de-licensed because marketing Glenlea wheat--. Because of its requirement of a weaker, lower-quality wheat type. But I liked it because of its unique, overly strong dough characteristic. It had good carrying capacity for lower quality, weaker varieties. Those varieties are not grown to a large extent in Canada. We are doing very well with CWRS varieties. They have not only the type of quality that we need, but also, they grow well under our fertility crop growing conditions.

MC: In all of this that you are talking about with triticale and these competitions between the favourite variety of the day of wheat grain, there always seems to be a search for improving and trying to solve problems in perhaps the processing end, leading to a consumer product. Implicit in what you are saying, there is always the search to solve problems. Could you tell us a bit about what those problems are? Perhaps it is in the processing—to produce a kind of bread product that satisfies consumers with different palettes around the world? What were those problems that you are really alluding to that your research and others were trying to address?

WB: The problems are many in addition to agronomic characteristics. There are problems related to processing, such as getting the maximum flour yield in the milling process.

MC: You mentioned agronomic problems, is this like the rust issue you were referring to?

WB: The rust issue.

MC: Tell us about rust. It is a nasty little creature, isn't it? Or is this totally out of your area, as it is mine?

WB: It is out of my area, but occasionally it comes into play in my area because under some conditions rust, especially in varieties that do not have rust resistance introduced by breeding, these varieties will show an effect on the constituents. Proteins will be affected in terms of quantity of protein, protein content, and in terms of the chemistry or the quality of the protein. Selecting varieties for rust resistance requires also careful monitoring for quality. In many cases the quality is not affected, but the yield is affected. The kernel shape and kernel size will be affected, which in turn affects the milling properties. The percentage of flour that is produced from a given sample of grain, this is affected, and if you go further, there have been affects noted on the chemistry of the components, which relate to the bread-making quality in the case of bread wheats.

MC: That is really fascinating. Being a consumer, I am thinking about the problems related to making bread and not thinking at all about the implications for some of these other sectors like the agronomic issues and the processing issues.

WB: There are two general approaches, as far as quality is concerned. One is to get the right quality by breeding. This brings in a science of genetics. You select the varieties that you want for quality and then cross that variety with another variety that has, maybe not the right quality, but the right disease resistance. You cross these two and pick out the ones that meet your requirements. That is one approach to improving quality of crops like wheat.

The other is through the processing approach. You take a variety and grow it because it has rust resistance or it produces high yield. You take that variety and modify it during processing to give the right quality that you want. Genetically you can modify by crossing a weaker variety with a stronger variety. Or you can take the variety that is useful for other reasons—flour yield during milling, flour colour. The Japanese might like it because it has certain--. So you can bring about this change by crossing, but that takes 10 to 12 years. Sometimes it is better to take a variety that has the other characteristics and modify the bread-making characteristics by physical or chemical means. That is another area that I spent quite a bit of time on, that is the use of chemicals to modify the baking quality of wheat flour, without going through the breeding process.

MC: How would that happen? How would you chemically modify? How did you work on that? In a simple consumer explanation?

WB: One of the chemical entities that is involved in bread-making properties is the presence of thiol SH groups in the proteins. You can modify the number of thiol SH Groups chemically by adding an oxidizing agent. An agent that has been used until recently for many years is potassium bromate. A few milligrams, say five to ten milligram-percent, of potassium bromate added to flour during the bread making process will eliminate this deficiency in the variety. So you correct for certain deficiencies by adding a chemical. There are several chemicals available on the market to do this.

Another flour improver is enzymes. Special enzymes can be added to improve. You can improve the quality of the flour by modifying it by adding a chemical or a bio-chemical during processing. Or you can obtain the appropriate amount of an active chemical by breeding and selecting. We have this technique well under control, and our breeders select parent varieties that have the right chemistry or require very little additional chemicals. This potassium bromate story is an interesting one. It is only recently that it had been banned when the Japanese have shown that it can cause cancer in mouse fed with potassium bromate. The chemical has been banned, although no one has been able to prove that the very minute quantities of this improver, potassium bromate, can cause cancer in animal experiments.

MC: Have there been a lot of changes in the way the processing end of the thing has been done that you have observed over the years?

WB: There has been a change, and now it is changed back. Twenty years ago, we were really keen on what is called mechanical development of dough. It was found that by increasing the mixing speed of flour-water dough, you can develop the gluten that is appropriate for gas retention in a bread system. This was introduced and the industry really jumped at it, but in a few years the texture—eating qualities of the bread—the texture, the crumb structure was fine and uniform, like Styrofoam, and the bread was not very popular. So we have gone back to the traditional sponge and dough process. Basically, there hasn't been a major change in the bread-making technology.

What has happened, and is happening, is that the number of different bread varieties has grown. High fibre content varieties, multi-grain varieties, and each of these changes that were introduced would bring many problems. For example, when you go from white bread to whole wheat bread, you lose some desirable texture, grain. So you have to go back and modify the process, modify the formula, add more fat, add more sugar to maintain the structure and yet have the additional fibre for example. There have been quite a few changes in that area. The mechanical development area that came in some 20 years ago and was so popular that most of the bread was being produced by this process has basically disappeared now.

MC: You mentioned the mechanical process and the sponge-and-dough process. Could you just elaborate a bit on those two so that listeners who may not be familiar with those two processes have a clear idea what you mean?

WB: An important feature of bread making is the development of the gluten to get the right rheology—viscoelasticity as we mentioned earlier. For many years, this development of the right dough was achieved by fermentation. Yeast produces CO2. This expands the dough and in three hours or so develops the type of dough structure that is most suited for the type of bread that we like. About, I guess in my time, maybe 50 years ago, it was found that much of the dough development can be produced by adjusting the mixing in the process of dough mixing, adjusting in two ways: speed of the mixture and the mixing time. These can be optimized so that you can develop the dough to the right structure by a short time of mixing, 10 minutes instead of three hours of development by fermentation. This would be a tremendous saving of time and money.

One thing that was not possible to resolve and that is to in mechanical development to maintain or produce the type of texture that we like in sponge-and-dough process. Gradually the market for mechanically-developed bread went down. Pretty well most of the bakeries now don't use the mechanical development. What usually happens in such situations is that there is an attempt to combine the good effects of one process with those of another. And indeed, it is possible to combine mechanical development and sponge-and-dough development and get the time saving of mechanical development with the texture of the traditional sponge-and-dough process.

MC: You say that is possible? Has it happened?

WB: Yes. Special flours are produced in the milling process that will have a small amount of chemical added that will assist in the development of the dough. Earlier I mentioned potassium bromate, which is an oxidizing agent. The improver that is used to improve the efficiency of mechanical development has the opposite effect of bromate. It's a reducing agent, sustained, an amino acid which has a thiol group on it. It has a reducing effect, so it does the opposite. Flour doughs that have in them added reducing agent develop mechanically quicker and produce a structure, not precisely identical, but very similar to the traditional structure, which is a variable size of the structure of the bread crumb.

MC: That is absolutely fascinating! There have been so many changes you have mentioned already in terms of processing, varieties and so on. Can you think of other major changes that happened over your career, not necessarily technology? It could be political, social, cultural, money or financial, other really key changes that stand out in your mind as being very important in terms of how you were able to do your research or not perhaps? Significant changes that you had to address?

WB: There have been a few significant changes in the wheat industry. We used to have a quality requirement equal to that of Marquis. Marquis was the gold standard, and that had been replaced in I think 1971 by Neepawa, and now I think recently—and somebody from the Grain Commission might have to confirm this—I think we have completely removed the varietal standard or CWRS wheat. The current statements are something like "It shall be acceptable according to standards of the varieties grown at the time." Whereas before it said, "Must be equal in quality to Marquis and Neepawa and so on."

MC: How has that impacted?

WB: I think it expanded the range of quality that is now permitted to be registered for our CWRS class of wheat. I don't know. There was another change that was being discussed, and I don't know how far the Grain Commission got with it, as far as the legislative part of the process, and that is the elimination of the requirement for vitreous kernels, the percentage of KVD storing.

MC: What is a vitreous kernel?

WB: It can be opaque, starchy, or vitreous. For a long time, we have had a percentage of vitreous kernels had to be defined. My colleagues at the Grain Commission have shown as far as milling and baking properties are concerned, vitreousness has no effect. So they proposed elimination of vitreousness as a grading factor. There is a table that specifies the various characteristics. One of them is vitreousness. It will be eliminated, and of course it is always useful to eliminate a characteristic because it eliminates another test that has to be made. A test that has to show certain value which adds to the additional work involved in testing new varieties because not only does this affect the grading process, it also affects the selection of varieties during breeding because they will have to meet these requirements.

MC: You have been talking about the whole issue of grading. You certainly were involved in some new methodologies of grading. Maybe you can tell us a bit about your work there in terms of grading?

WB: It is an area that we have not paid too much attention. The possibility of grading grain wheat by electronic means is there. It is used in many industries, but it has not come to the grain industry. Although the work that Digvir Jayas is doing is coming close in the application of digital imaging to the grain industry. We have shown that digital imaging can be used to segregate, to identify varieties by external features: shape, size, colour. Also, by using transmitted light instead of reflective light one can obtain information on the internal structure of the grain kernels. Various types of physical damage can be detected and measured quantitatively and can be related to the grade. A new grading system would have to be set up to reflect the characteristics that are measured.

When we had our chair program the objective was to replace the inspector's eye in the grading process with an objective methodology based on digital image analysis. Take a photograph, change the photograph to digital form and then use that to set up your parameters in terms of digital properties. It is an expensive technique, but I think some aspects of it will come to the grain industry.

MC: What was your contribution in this movement to a more objective way of doing it than the visual method?

WB: We showed that different grades can be distinguished from one another by digitizing. We showed that different levels of amylase, sprouting damage, can be measured by this process. Some of the basic requirements of grading can be done by digital image analysis. We would like classes of wheat, and if you want to throw in triticale, because these kernels are distinctly different can be distinguished. Durum wheat from CWRS can be distinguished mechanically. We had hoped to be able to distinguish varieties within a class. Do you understand what I mean?

MC: The varieties within a class being--?

WB: Each class of wheat is made up of many varieties, maybe 15 or 20 varieties. These varieties have to meet certain criteria in order to be registered for that class.

MC: Okay, I get it now.

WB: Back to digital image analysis, our early work showed that we can distinguish durum wheat from CWRS wheat by digital image analysis. Put this sample a mixture of wheat and put it through the machine and the machine gives you a readout of 10 percent undesirable varieties or whatever, or it can direct the loading the binning of the variety by the information that comes from the computer. One thing we hoped to do because there is a background of interest is to identify varieties within a class.

MC: Were you able to do that?

WB: We were able to do that, but not well enough to make it practically useful. The difference among the varieties within a class is too small for even for the computer camera to pick up. Some varieties have unique characteristics: unique shape, size, and the groove. They can be identified by digital image analysis. But some varieties you could have three or four varieties within a class that are so similar that the inspectors can't identify but even the digital imaging process cannot identify.

MC: Our tape is running out of time. I think that we should, if possible, chat with you to pursue some of these other issues. I would like to know about the industry in regard to this grading methodology, its acceptance or reluctance to accept it. Maybe we could meet again and talk about this.

End of interview.