Dietary fibre in human nutrition: the problem of providing nutrition advice

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Abstract

Purpose – The aim of this paper to explain the difficulties associated with applying the science of nutrition in formulating advice to protect public health, using the example of dietary fibre.

Design/methodology/approach – Based on this review of relevant literature published between 1953 and 2006, the first section traces the history of attempts at constructing useful definitions of dietary fibre. Then the problems of measurement of the fibre content of foods, measurement of fibre intake in individuals and with testing for correlations with disease, are outlined.

Findings – The equivocal nature of current definitions of dietary fibre, and the lack of accuracy, validity or reliability of methods of determination, have been major limitations to developing an understanding its role in protecting human health. Perhaps more than for any other dietary constituent, the elucidation of the science describing the role of dietary fibre in human nutrition has been confounded by both known and unidentified variables.

Practical implications – This paper reflects an increasing scientific awareness that developments in nutrition are subject to the limitations of methods of analysis and research design. It explains why the processes of scientific investigation are often slow to reveal important relationships between dietary factors and health. This presents some difficulties for authorities charged with promoting health protective eating behaviours.

Originality/value – Although it has not been possible to unequivocally quantify dietary fibre or its effects on human metabolism, the research provides strong support for choosing a wide range of fresh or minimally intact plant food sources to protect health, as recommended in the FBDG's promoted in many countries around the world. The health protective effects may be achieved with moderation of the information disseminated about dietary fibre, particularly via the marketing of manufactured foods supplemented with fibre isolates.

Keywords Diet, Public health, Nutrition, Research

Paper type General review

Introduction

The widespread public concerns about diet related health issues always begs the question: why is it so hard to provide effective dietary advice? Of course, there is no simple explanation. The personal and environmental factors that affect food choice vary significantly between individuals, even within a community or for those sharing similar cultural experiences. These factors have been explored in a growing body of research so far. But probably one of the major limitations to developing useful nutrition advice is the science from which advice is derived. It has not been possible to offer the public responsible and definitive statements about effective ways for preventing most diet-related chronic non-infectious diseases. There are many factors that confound elucidation of the science of nutrition, evident by tracing a path through the research. Dietary fibre is an interesting and still emerging scientific concept, so that important milestones in research are readily accessible in the scientific literature. Examining the

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research about the health protective effects of dietary fibre provides some insights into difficulties interpreting the science into useful and responsible public nutrition advice.

Reflecting changes in its development as a scientific concept, dietary fibre has been named in many different ways, including the terms bulk, bran, roughage, plantix, plant residue, unavailable carbohydrate (Przybyla, 1988), and later as non-starch polysaccharides. It was Hipsley (1953) who first used the term dietary fibre in scientific research in a study of toxaemia of pregnancy, a term still widely used. Like the trends in naming this concept, there have been many attempts at defining dietary fibre to clarify its nature or function. This paper traces the progress towards developing an unequivocal definition of dietary fibre and reliable methods of determination, as a basis for research to elucidate its role in human health.

Botanically based definition

According to numerous classical definitions, the absorbance of a chemical entity in the human body is one important characteristic that distinguishes nutrients from non-nutrients. An anomaly for nutrition research, dietary fibre could not be classified as a nutrient since its role in the body was apparently dependent on its non-absorbance. For a very long time, research into a non-nutrient was not regarded as important by the scientific community. In fact, the apparent lack of scientific interest in the role of dietary fibre world-wide even up to the 1960s (Slavin, 1990) has been attributed to this "persistent belief in the inertness and non-nutritive character" of dietary fibre (Van Soest, 1978, p. S12). Social attitudes also influenced research in this area. Perhaps a legacy of Victorian attitudes, it was considered distasteful by western cultures to deal with the subject of human waste, even in scientific research, until later in the twentieth century (Kellock, 1985). Attributed to the cumulative effect of these factors, few scientific papers were published in Australia (Mugford and Chambers, 1993), reflecting a general trend in fibre research at the time.

Conventions within science require that variables are defined in ways which allow researchers to measure them quantitatively. An early approach to a quantitative definition was based on botanical classification. Rubner, a student of Atwater, recognised that the techniques he developed measured hemicellulose and lignin, as well as cellulose, which comprised the "cell membranes" of plant foods (Trowell, 1978a). Throughout subsequent research, dietary fibre was assumed to comprise only these components, so that the other fractions located elsewhere in the cell were ignored (Trowell, 1978a). While cellulosic materials are a major component of most native forms of dietary fibre, other components capable of inducing effects attributed to dietary fibre are found in the cell wall and in other cell structures. With an increasingly wider range of chemicals recognised as contributing to the dietary fibre effects, the broader term of non-starch polysaccharide (NSP) was introduced to include them. Nonetheless, this strong association of fibre with cellulosic materials and with cell wall structures in particular, has prevailed even into the recent literature.

Defining in terms of digestibility

Attempts were made to distinguish dietary fibre from other carbohydrates in terms of the energy available on digestion. This idea can be traced to work undertaken much earlier by Atwater who measured available and unavailable nitrogen in food proteins (Trowell, 1978a). The concept of availability was attractive because digestibility could be quantified in various ways (Przybyla, 1988), and could distinguish dietary fibre from other food components. This traditional concern of science with developing definitions or concepts, which can be tested in technical and manageable ways, influenced the development of the concept of dietary fibre in particular.

Defining in terms of endogenous enzymic hydrolysis

Much of the early research effort was almost solely due to Trowell and Burkitt who published many articles describing the apparent relationship between a high dietary fibre intake and low incidence of various degenerative diseases in African countries (Trowell, 1960; Slavin, 1990). Later, they extended their research to test this correlation for other groups around the world (Burkitt, 1971, 1973; Trowell, 1972, 1973, 1978a). It was Trowell who paid particular attention to defining this concept (Trowell, 1974, 1976, 1978b).

While collaborating with others working in the field, Trowell (1972, p. 926) described dietary fibre as "the skeletal remains of plant cells that are resistant to hydrolysis by enzymes of man". Only a few years later, this definition was described as "inadequate" because some storage polysaccharides were also resistant to digestion by gastrointestinal enzymes (Trowell *et al.*, 1976, p. 967). Galactomannan, for instance, is located within the cell rather than the cell wall, and had been shown to induce some of the physiological responses associated with dietary fibre. As a consequence, fibre was re-defined as "the plant polysaccharides and lignin which are resistant to hydrolysis by the digestive enzymes of man" (Trowell *et al.*, 1976, p. 967).

A few months after Trowell published his enzymically based definition, Spiller and Fassett-Cornelius (1976) presented a different argument for a change in nomenclature. As a mixture of both fibrous and non-fibrous substances, the term fibre was considered inappropriate. They suggested plantix, a term describing the matrix of the undigested components of plant materials remaining after digestion (Spiller and Fassett-Cornelius, 1976, p. 934). This definition was significant for its specific reference to human physiological processes and potential to include a broad range of unnamed components.

Defining in terms of microbial fermentation

Efforts to quantify fermentability of fibre through microbiological activity in the bowel met with "immense methodologic problems" (Eastwood, 1987, p. 194). Identifying the microflora of the intestine relied on maintaining strictly anaerobic conditions for growth during experimental investigation, a relatively difficult task at the time (Roth and Leitzman, 1985). Without evidence of a variation in faecal flora with fibre intake using the techniques available, a microbiologically based definition did not provide the foundation for quantifying the effects of fibre intake on health. Technical limitations were clearly affecting the development of the science of dietary fibre even late in the twentieth century.

Balance between endogenous and microbial enzymic hydrolysis

Building on the work of Trowell, Bright-See (1988) concluded later that it was resistance to the endogenous secretions of the human digestive tract, which distinguished substances classed as dietary fibre. This definition did not exclude those substances that are susceptible to enzymes produced by bacteria in the colon, so dietary fibre could be considered to be fermentable as well as indigestible. This finding led to the identification of the soluble forms of dietary fibre, with their higher water holding capacities and greater vulnerability to degradation (Eastwood, 1987). Focusing on the overall process of hydrolysis allowed distinctions to be made between different forms of dietary fibre according to the site of digestion or fermentation, energy yield and integrity on excretion. The most soluble forms of fibre are digested by endogenous enzymes in the upper part of the gastrointestinal tract, while other forms are degraded to varying extents by the bacterial flora in the large bowel (Schneeman, 1989).

Rather than simplifying the concept however, a definition based on the degree of hydrolysis by both endogenous and microbial enzymes broadened even further the range of food components that might be classed as dietary fibre. For instance, an enzyme deficiency or the presence of enzyme inhibitors in food could mean certain components were indigestible, effectively a form of dietary fibre for some individuals (Wahlqvist, 1989; Schneeman, 1989). Further, substances rendered indigestible through the chemical and physical changes induced by normal food processing operations could be classed as fibre. This included resistant starch, a by-product of food processing, recognised in 1980s as contributing to the health protective fibre effect (Akerberg *et al.*, 1997)

Defining in terms of chemistry

Describing the concept in chemical terms was an alternative to a microbiologically based definition that had introduced new problems to solve before it could be applied. However, a chemical definition relies on the identification, extraction and measurement of a specific group of similar components. A major component of dietary fibre, cellulose is comprised of glucose monomers like starch but, due to the different glycosidic linkages, is not vulnerable to the α-glucosidases. However, even the broad chemical descriptor "non-starch" polysaccharide is inadequate as a unifying chemical classification, because some fibre molecules are comprised of monomers other than glucose in various arrangements, with each fraction requiring different methods of extraction and measurement.

The property of low solubility has traditionally been associated with the unique chemistry of the molecules grouped as dietary fibre. However, there are significant variations in the points of linkage and component monomers which affect the "kinking" of the molecules (Olson *et al.*, 1987; Ink and Hurt, 1987), resulting in a range of levels of solubility. It was postulated that solubility might correlate with the health protective effects of dietary fibre in a way that digestibility and fermentability had so far been unsuccessful. So, by the 1970s, the effects of consuming the more soluble forms of dietary fibre found in agar, alginates, gum arabic, locust bean gum, gum tragacanth, carrageenan, guar gum, pectin, xanthum gum, and the β-glucans of oats and barley, were being investigated. In particular, research focused on the capacity of soluble fibre to bind bile acids which otherwise act as co-carcinogens in the bowel (Gerhardt and Gallo, 1998). Despite the research effort, the levels of solubility did not explain effects in the body. In fact, more recent research has indicated that insoluble dietary fibre also has bile acid binding capability (Story and Savaiano, 2001). In retrospect, the arbitrary distinction between soluble and insoluble fibre has been less than useful as a basis for building an unequivocal chemically based definition in the process of elucidating the science of dietary fibre.

Defining in terms of physiological effects

As far back as Hippocrates, references to dietary fibre provide evidence that its physiological effects were known (Bookwalter, 1987). Even the famous playwright Shakespeare was aware that fibre remained undigested as it passed through the alimentary tract, evident in an analogy is his play *Coriolanus* (Act I, Scene I). But in most of these early observations, the effects of fibre intake were described without reference to any health benefits. Perhaps it was Beaumont who can be credited with the first claim in 1883 that including vegetable fibre in the diet prolonged life (Anderson *et al.*, 1990). Just a little later, in the early 1900s, Graham and Kellogg, famous for biscuit and breakfast products respectively, publicly promoted the value of high dietary fibre intakes for protecting health (Hammond, 1987; Slavin, 1990). Around this time, there were a few medical practitioners who took various steps to overcome "intestinal stasis" (Smith, 1982). For the fortunate few patients, consumption of foods high in dietary fibre was recommended, rather than the life-threatening surgery and other drastic measures proposed by these practitioners. However, hypotheses about the physiological effects of dietary fibre remained largely untested through these sporadic non-scientific approaches.

During the twentieth century, an increasing number of biochemical and physiological processes were implicated in explanations of the role of dietary fibre (Southgate, 1978; McKenzie, 1990). Various types of dietary fibre could induce changes in stool weight, faecal bile acid secretion, production of short chain fatty acids or serum cholesterol levels. Some insoluble fibre sources, such as wheat bran, were known to increase stool weight without influencing the production of butyrates, which may counter the promotion phase of carcinogenesis in the epithelial cells of the bowel (Niba, 2002). The soluble fibres gum arabic and pectin decrease serum cholesterol levels, but have no effect on stool weight. Both insoluble wheat bran and the soluble fibre in gum tragacanth increase stool weight, but have no effect on serum cholesterol levels. Rice bran is virtually devoid of soluble fibre, but had been shown to bind bile acids and lower serum cholesterol levels (Normand *et al.*, 1987), characteristics of the soluble dietary fibres. The effect on glycaemia of different types of dietary fibre through moderating insulin requirements still remains to be established (Kalkwalf *et al.*, 2001) although there has been some progress with establishing links between whole grain cereal intake and insulin sensitivity (McKeown, 2004). Clearly, defining dietary fibre in terms of its effects on the human body has not provided a simple approach to defining the concept.

More than a problem of definition

Without a universally accepted, unequivocal definition, dietary fibre has been conceptualised according to "the investigator's fancy" (Heller and Hackler, 1978, p. 1510), and more specifically, according the methods of measurement selected (Baer *et al.*, 1997). This hindered progress (McConnell *et al.*, 1974) particularly because research outcomes could always be challenged, limiting their contribution to the science of dietary fibre. However, there has been some progress.

Recently, the Institute of Medicine (USA) was commissioned to develop a definition for dietary fibre (Jones *et al.*, 2006). Reflecting the developments in nutrition and food technology, this new definition "includes plant cell wall and storage carbohydrates common in foods, and includes natural and manufactured or isolated and low molecular weight carbohydrates as functional fiber" (Jones *et al.*, 2006, p. 33). Although preferred by the expert committee, the incomplete knowledge about the physiological effects due to dietary fibre could not provide a firm basis for a unequivocal definition in these terms. In the interim, properties of food fibres can be characterised in terms of solubility, glycaemic index and bulking effects, along a continuum within the very diverse field of dietary carbohydrates (Schneeman, 2001). While this adds to the complexity, integrating both chemical and physiological dimensions may lead to a more useful definition of a concept because it accommodates the diverse range of properties of dietary fibre. With this progress towards a definition, other barriers to understanding the role of dietary fibre become more apparent. Testing long held assumptions or emerging hypotheses about the relationship between dietary fibre and health has also been delayed due to problematic research design and unreliable composition databases.

Limitations of research design

Dietary fibre research is confounded by the apparent dependence of outcomes on the study design. Researchers found significant negative associations between the incidence of colon cancer and fibre intake in a review of epidemiological studies (Greenwald *et al.*, 1987). However, in several case-control studies, the association between fibre intake and colon cancer was insignificant, and even positive in one instance (McKeown-Eyssen, 1987). More recent reviews of major studies reveal this same anomaly (Ferguson and Harris, 2003; Trock *et al.*, 1990). One explanation is the extrapolation of outcomes of typically short term or cross sectional studies to predict long term effects associated with the slow paced initiation of diseases which may be associated with low fibre intakes (Schneeman, 2001; Story and Savaiano, 2001; Taylor *et al.*, 1999). Failure to account for the possibility of a threshold level of fibre intake for protective effects to become evident (Ferguson and Harris, 2003; Monro, 2004) may explain equivocal outcomes of research.

An ongoing problem with observational epidemiology is the many confounding variables, particularly in researching the health protective effects of dietary fibre (McKeown-Eyssen, 1987; Katan, 1996). As with any study of trends in populations consuming typical mixed diets, controlling for interactions between dietary components is difficult. The situation for dietary fibre research is particularly complex, given the importance of reactivity after digestion, including potentially synergistic interactions with other non-digestible carbohydrates (Niba and Niba, 2006) and other dietary components (Baer *et al.*, 1997). The failure to distinguish between the effects due to total carbohydrate intake and due to the dietary fibre fraction is a major limitation of earlier research (Mann, 2001). The importance now attached to the type as well as the total amount of carbohydrate consumed (Schneeman, 2001) may lead to substantial progress in this field of research.

The potential of dietary fibre to moderate obesity and associated diseases may be due to its inhibitory effect on fat and protein digestion (Baer *et al.*, 1997), or due to a reduction in overall energy intake when it replaces or reduces the intake of typically higher fat and higher protein animal products (Bright-See, 1988; Floch *et al.*, 1986; Howarth *et al.*, 2001; McKeown-Eyssen, 1987). In reviewing their own research, a positive association between fibre intake and colon cancer reported in the earlier study (Potter *et al.*, 1982) disappeared when alcohol and fat intakes were controlled (Potter and McMichael, 1986). Other non-dietary lifestyle modifications may be associated with a voluntary increase in dietary fibre intake, further confounding the interpretation of findings (Chandler, 2006).

The typical underreporting of intake in some food categories by subjects (Schneeman, 2001) may inversely affect estimates of dietary fibre in particular. The variation in available fibre in parts of plants means it is necessary to know the proportion of the whole fruit, vegetable and cereals consumed by subjects. In most studies, this information is not collected and would be difficult to establish retrospectively.

Finally, it seems that the benefits of dietary fibre may vary considerably from one individual to another. Obese individuals (Howarth *et al.*, 2001) or those with higher LDL serum cholesterol (Kris-etheton *et al.*, 2002) or greater insulin resistance (McKeown, 2004) may benefit more from a high fibre diet, suggesting that outcomes are influenced by the characteristics of the subjects included in the study.

Inaccurate composition databases

Scientific research requires assessments of intake, in turn dependent on accurate databases describing the fibre content of foods. As well as relying on a useful definition of the concept, establishing an accurate database is an analytical problem associated with measuring proportions of a well-characterised range of chemical entities. Further, a single analytical method would allow comparisons of results of different studies and pooling of research data for more powerful testing of correlations.

For a long time, crude fibre values were used to describe fibre content of foods because they were the only chemical measures available (Heller and Hackler, 1978). Even if crude fibre values had been adequate as a measure of total dietary fibre, there were substantial variations in values reported from laboratory to laboratory when using the Association of Official Analytical Chemists "Crude Fibre" Procedure (Association of Official Agricultural Chemists, 1990), the most commonly used method. The validity of total fibre values was further compromised if lignin, hemicellulose or cellulose were present in relatively high levels because of the failure to recover very substantial proportions of these fractions so that, for instance, the total fibre content of wheat bran may have been underestimated by as much as four times (Van Soest, 1978). Researchers recognised this so that the methodological limitations were used often to dismiss unexpected results.

Awareness of the inadequacies of "crude fibre" as a measure of fibre content led to many new methods for determination (Baer *et al.*, 1997). They were designed to distinguish between different fibre fractions but results depended on the method selected (Englyst and Cummings, 1990). Different determinations could be due to a loss of fibre components at various points in the extraction process, incomplete acid hydrolysis of the fibre during extraction, or the inclusion of non-fibre substances at the recovery stage (Marlett, 1988). The Englyst method measures only the NSP's. while the Association of Official Agricultural Chemists (1995) method includes lignin and resistant starch (British Nutrition Foundation, 2004), so that there is an average difference of 35 per cent in the total fibre values measured (Butler and Patel, 2000). The validity of research that relies on fibre composition data, typically compiled from many sources using different methods, can be questioned on this basis.

Recognising the role of soluble dietary fibre required measurement of a whole new range of substances including pectin. This heterogeneous mixture of molecules with various sidechains, degrees of hydrogen and covalent bonding, and degrees of esterification, added to the problems of determination (Reiser, 1987). For most of the standard methods, pectic substances along with variable amounts of hemicelluloses and gums, were not included (Olson *et al.*, 1987). As a consequence, estimations of fibre content of foods high in pectin or other forms of soluble dietary fibre were inaccurate. Marlett *et al.* (1989) confirmed the method dependence of values of soluble dietary fibre in a variety of foods, as well as the overestimation due to the inclusion of up to 1 per cent starch in the fractions recovered from gravimetric and chemical methods of determination. While some progress has been made, many methodological problems remain unresolved (Jones *et al.*, 2006).

Some time ago, Potter (1988) noted that most studies relied on a range on databases, with entries calculated using different methods with significant variations reported in the compositions of foods. This situation has not changed (Butler and Patel, 2000), and remains a significant limitation for investigating the health protective effects of dietary fibre (see for example Saura-Calixo and Goni, 2004; Ajani *et al.*, 2004; Chandler, 2006). However, the problem extends beyond the inaccuracy and unreliability of methods of determination. The complex nature of food means that there are many variables affecting amounts and reactivities of the fibre component.

Influence of processing on reliability of fibre values

Food processing has implications for the reliability of databases because it affects the physical form of the fibre and chemical reactivity of the molecules. For instance, fine bran has lower water holding capacity (McConnell *et al.*, 1974) than coarse bran (Eastwood, 1987), and consequently different effects on colonic function, similar to the effect observed with apple puree and whole fresh apple (Wahlqvist, 1989). Recognised for some time, supplementation of foods with fibre extracts complicates the problem (Przybyla, 1988) because the processing involved in preparing the isolates changes the form and reactivity of the molecules.

Lack of scientific awareness of the different effects of processing on fibre reactivity may explain why research outcomes were not qualified in terms of the type and condition of the fibre consumed in 40 epidemiological studies published in the period 1970 to 1986 (Greenwald *et al.*, 1987). Even since then, many studies using encapsulated fibre or food supplemented with fibre extracts have not acknowledged the possible effects of the condition of the fibre (Burley *et al.*, 1990; Krotkiewski and Smith, 1990), until quite recently (Howarth *et al.*, 2001).

The problem extends beyond the functionality of the fibre. Using extracted forms in controlled studies means the fibre is administered without cell constituents with which it occurs naturally. Failing to control for the protective effect of the antioxidant vitamins C, A or E, folate or minerals found in fruit, vegetable and whole grain cereals may be a significant omission (Bright-See, 1988; McKeown, 2004) and could explain contradictory outcomes reported in some recent major studies (Ferguson and Harris, 2003). This also applies to other bioactive components, such the phenols and indoles of the cruciferous vegetables or phytic acid in whole grain cereals, whose protective effects have been recognised for some time (Floch *et al.*, 1986; Wong, 1986). Nonetheless, processing of plant foods may also have a positive effect if it leads to the release of potentially antimutagenic components that would otherwise not be available (Ferguson and Harris, 2003)

Processing also affects fibre content when it changes the blend of botanical components included in the food (Bookwalter, 1987). This means that the reliability of databases depends on information about the actual ratio of parts of the whole fruit or cereal included in the product, usually not available. While processing is typically associated with removal of dietary fibre from foods, dietary fibre values may increase if processing renders starch resistant to digestion (Englyst and Cummings, 1990), or when non-reducing sugars and protein interact in the Maillard reaction (Pomeranz and Shellenberger, 1971) to form indigestible products. Whether these fractions are included in the fibre determination and consequently the database depends on the determination methods used (Englyst and Kingman, 1988; Jones *et al.*, 2006).

Influence of genetic and environmental factors on fibre values

Fibre content depends on growing conditions, variety and maturity of plant species (Southgate, 1978). The extent to which these variations might be detectable by a particular method of analysis, or the extent to which average values are reliable estimates, determines the usefulness of recorded values of fibre content of foods. Nearly three decades ago, the development of new plant varieties through selective breeding, with associated intentional or unintentional changes to fibre present, was recognised as an added complication (Eastwood, 1978). Now genetic engineering of plant foods is likely to add to the problem of establishing a reliable and accurate database.

Implications for public nutrition advice

Until more reliable databases, methods of fibre determination and methods of collecting information about food intake are available, there will always be opportunities to disregard any unexpected outcomes which challenge the consensus view about the role of dietary fibre. Such influences may have discouraged a more careful approach to the interpretation of unexpected results to explore the relationship between dietary fibre intake and health.

Some of the limitations of current databases may be overcome with the progress towards a definition that now embraces the diverse effects of dietary fibre. At the same time, this presents new challenges for developing accurate methods for determining fibre content. Further, genetically engineered ingredients or more complex high fibre food formulations introduce new variables to accommodate in fibre determinations. Perhaps in vivo methods will ultimately be shown as the only reliable way to account for the influence of the often very subtle differences in fibre intake in a mixed contemporary diet.

Commercial interest in the relationship between dietary fibre and health is reflected in the production and promotion of a broad range of value-added fibre fortified foods. The associated advertising often implies a strong message about the potential health benefits of the product. However, it seems unlikely that specially formulated manufactured foods supplemented with fibre extracts or with raised levels of resistant starch will be shown to offer the health protective benefits currently attributed to dietary fibre derived directly from whole natural food sources.

Currently, there is relatively limited economic incentive to promote natural sources of dietary fibre, typically minimally processed fresh plant foods providing antioxidant vitamins and other bioactive agents. To avoid apparent anomalies or ambiguities communicated through marketing messages for manufactured products, there is a need to raise public awareness that different sources of dietary fibre may have different health protective benefits. This can be achieved within the framework of the food based dietary guidelines if some distinctions are made. On the basis of the equivocal science about the role of dietary fibre, messages about fibre supplemented processed products should be qualified so that consumers recognise them as likely to be less effective alternatives for reducing the risk of diseases associated with inadequate fibre intakes. Making such distinctions could strengthen the impact of public nutrition advice about choosing whole fresh fruit, vegetables and cereals, a recommendation that is supported unambiguously by the outcomes of research over many decades.

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