Common Beans

A sustainable and inexpensive super food to fight against CVD

Legumes, such as common beans, are well known for their health benefits, including their ability to lower blood cholesterol and lipid levels. However, prior to consumption, beans need to be cooked or processed. These techniques often cause changes in the bean matrix, which can potentially influence their positive physiological effects. Dr Cristina Fernández-Fraguas, Assistant Professor at Virginia Polytechnic Institute and State University, is investigating how the structure of plant tissues contributes to improved nutrition, health, and reduced risk of chronic disease.

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Cardiovascular disease (CVD), a broad term encompassing multiple disorders affecting blood vessels (e.g. heart attack, stroke), is the leading cause of death globally, causing 17.9 million deaths each year. CVD is also a major economic burden: the global cost of CVD is set to rise from approximately $863 billion (2010) to $1044 billion by 2030.

Dietary interventions and lifestyle modifications are more appealing solutions than drug therapy to reduce the long-term incidence of CVD, especially since diet might simultaneously have positive effects on obesity and type-II diabetes. Many of the dietary patterns proposed have similar underlying themes – for example, fewer sources of saturated fat and more fruit, vegetables, wholegrains and legumes.

SUSTAINABLE AND NUTRITIOUS LEGUMES

Dietary pulses (the edible dried seeds of legumes, e.g. chickpeas, lentils, beans and peas) are well known for their nutritional and health benefits, as well as their impact on agricultural sustainability. The demand for plant-based proteins is higher than ever and pulses are an excellent and inexpensive source of proteins. This makes them major protein substitutes for meat products, thus contributing to sustainable farming and nutrition.

Furthermore, legumes provide increased amounts of complex carbohydrates including fibre. The American Heart Association encourages consumption of fibre, aiming for around 30g/day; however, most adults in the US only consume around half this. Common or dry beans (*Phaseolus vulgaris* L.) have two to three times more fibre than other dietary staples (e.g. cereals), and therefore can play a major role in helping people to meet these recommendations.

There is epidemiological evidence that consumption of pulses, particularly beans, has benefits for body weight control, regulation of postprandial glucose and insulin response, and blood cholesterol levels. It is thought that the high fibre content of beans is important in conferring these health benefits.

However, the precise mechanisms by which dietary fibre and beans lower blood cholesterol levels is not yet fully understood. Additionally, potential modifications to the bean matrix that occur during domestic or industrial processing of beans might impact their nutritional quality, their dietary fibre functionality, and ultimately their ability to lower cholesterol and lipid levels and prevent CVD.

It is this that Dr Cristina Fernández-Fraguas, Virginia Tech, is exploring in further detail. Her work focuses on investigating how the structure of plant tissues and processing technologies influence the breakdown and behaviour of nutrients within the human digestive tract.

DIETARY FIBRE, CHOLESTEROL AND BILE SALTS

Dietary fibre is the edible part of plants that is not digested nor absorbed in the human small intestine and reaches the colon where it is fermented by the gut microbiota. Dietary fibre can be divided into insoluble and soluble forms; the latter is able to dissolve in water and create gel-like networks in the intestine.

One of the main ways that soluble fibre might lower serum cholesterol is through sequestering or retaining bile salts (BS). Bile salts are biological detergents made in the liver from cholesterol, stored in the gallbladder and released when a meal is consumed; they then travel through the intestine, aiding fat (lipid) digestion. Almost 95% of primary BS are reabsorbed in the last section of the small intestine and recycled back to the liver in a process known as enterohepatic circulation. The remaining 5% of BS continue to the colon where they are transformed into secondary BS. The presence of fibre in the small intestine has been shown to reduce the amount of BS that are re-absorbed into the enterohepatic circulation. In order to replace the BS that have not returned to the liver, due to sequestration by fibre in the small intestine, the liver uses cholesterol to synthesise new BS, thus lowering blood cholesterol.

THE BEAN MATRIX

Interestingly, not all foods that contain fibre have the same health outcomes. Dr Fernández-Fraguas hypothesised that the bean matrix might influence the action of their dietary fibre, which is likely to involve complex processes and interactions. The food matrix describes the complex physical organisation of the food, which contains and/or interacts with food components, and exhibits a different functionality and behaviour than the isolated food constituents.

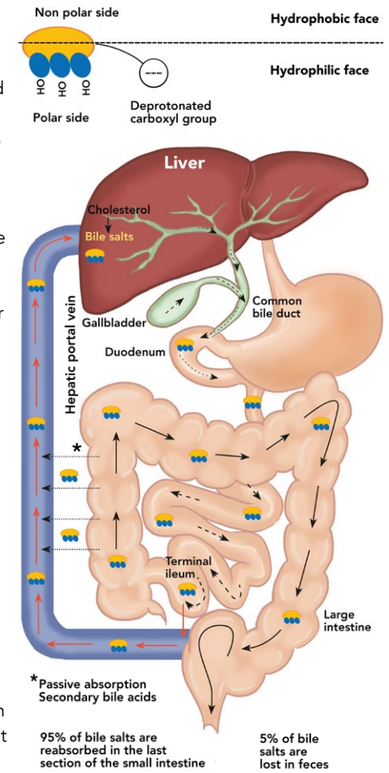

Figure 1. Bile salt structure (top) and enterohepatic circulation mechanism (bottom).

Beans have a complex and heterogeneous matrix characterised by a thick and resilient outer cell wall that protects an inner cytoplasmic matrix. This inner matrix contains most of the seed's nutrients (starch granules and proteins), whereas the cell wall comprises a mixture of fibres (cellulose, hemicellulose, pectin) providing structural support.

Consumption of dietary fibre and/or beans has been closely linked with reduced cholesterol levels and CVD risk.

Dr Fernández-Fraguas' research team has used an interdisciplinary approach combining microstructural and physicochemical characterisation of beans, coupled with an *in vitro* digestion model mimicking the human upper-gastrointestinal tract (mouth, stomach, small intestine) to investigate whether/how soluble fibre and other major bean components, isolated and as a whole, contribute to the retention of BS, and the role played by the bean matrix in this process. Findings from this study have shown that insoluble fibre, resistant starch and bean proteins add to the BS-sequestering effects of bean soluble fibre. Her research also indicates that the resilience of bean cell walls impacts the ability of bean constituents to retain BS during *in vitro* digestion. This indicates the need to evaluate each of these components separately and, more importantly, to consider the food in a more holistic manner, accounting for the whole bean matrix.

MECHANISMS OF BILE SALT RETENTION BY BEANS

The findings also confirmed that different mechanisms can help explain how beans are able to retain BS. Due to its viscosity and gel-forming properties, soluble fibre might form a network that traps BS, resulting in considerable BS retention.

However, despite bean proteins also showing high BS-retention, they did not increase the viscosity of the simulated intestinal fluid. Hence, the team hypothesised that non-digested and/or hydrolysed proteins molecularly associate or bound to BS. Taking into account the different molecular structure of BS, the team also evaluated the kinetics of BS-release to identify the binding preferences of bean components. They found that bean materials preferentially bound to more hydrophobic ('water hating') BS, such as chenodeoxycholates. This supports the hypothesis of hydrophobic molecular interactions between bean proteins and BS, and suggests that the formation of micelles (spherical structures built by BS and driven by their hydrophobicity) plays a significant role on the ability of beans to retain BS.

IMPACT OF COOKING AND PROCESSING METHODS ON FOOD STRUCTURE

Before being consumed, beans require some form of cooking or processing, which could influence the bioactivity of bean components, and ultimately their health benefits. For example, the cholesterol-lowering activity of β-glucans, a type of soluble fibre found in oats and barley, has been accepted as a valid health claim in non- or minimally processed forms of these grains. Therefore, another goal of the research done at VT was to evaluate how potential modifications of the bean matrix that occur during cooking and processing, translated to the ability of beans to retain BS and modulate fat digestion *in vitro*.

Concerns around ultra-processed foods and their negative impact on health have increased over recent years. Hence, further studies by the Fernández-Fraguas research team evaluated the effect of milling combined with high-hydrostatic pressure (HHP), a minimal processing technology, on the BS-binding ability of beans, and how this related to changes in bean microstructure, viscosity and dietary fibre content.

HHP is a green non-thermal process that applies high pressure (the equivalent of piling fifteen, 5 tonne elephants on top of

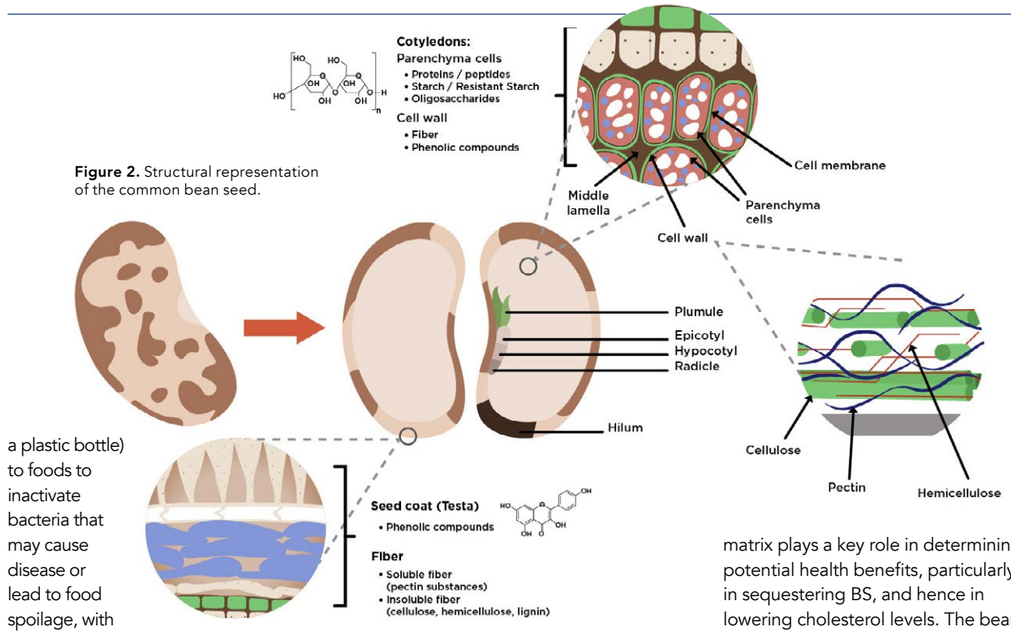

Figure 2. Structural representation of the common bean seed.

a plastic bottle) to foods to inactivate bacteria that may cause disease or lead to food spoilage, with minimum loss of sensory and nutritional properties. Dr Fernández-Fraguas' work is the first to explore the impact of HHP on the biological functionality of common beans related to cholesterol-lowering properties; the study compared HHP processing with domestic cooking, a boiling treatment at atmospheric pressure.

For the first time, it was demonstrated that while boiling (15 min or 2 h) significantly reduced the BS-binding efficiency of beans, HHP processing preserved and/or improved BS-retention depending on the pressurisation level and length; the most effective treatment combined the highest pressure (600 MPa) with a short time (5 min). Even if these HHP conditions reduced the content in insoluble fibre, microscopy analysis showed that boiling disrupted the bean cell wall integrity, protein matrix and starch granules more severely than HHP. The partial disruption of the cell wall and the formation of loosely packed starch-protein-fibre complexes during HHP (600 MPa/5 min), assisted by an increased cell wall permeability and porosity, may have resulted in a greater exposure of fibre components to BS.

This study concluded that a combination of compositional and structural factors triggers the BS-retention capacity of beans. Specifically, the degree of disintegration of the cell wall, protein denaturation and starch gelatinisation play an important role in BS-binding efficiency. This is possibly due to promoting the formation of starch-protein-fibre networks of varied compactness that provide binding sites for BS.

The researchers have also demonstrated that the different impact of pressure-time combinations on those factors translated into differences in functional and technological properties (i.e. gelling and emulsifying behaviour, water-holding and oil-binding capacity) which could increase the versatility of beans. By using this clean-label technology, the time for food preparation could be reduced and bean ingredients could be included in a wide category of food formulations, partly replacing existing additives.

When evaluating potential health impacts of a complex food matrix like beans, it is important to consider how the food is structured and processed and not just their nutrient content.

HARNESSING THE HEALTH BENEFITS AND VERSATILITY OF BEANS

Through her research, Dr Fernández-Fraguas has demonstrated that the bean matrix plays a key role in determining potential health benefits, particularly in sequestering BS, and hence in lowering cholesterol levels. The bean matrix is also relevant for modulating the digestibility of fats, as BS are major players in fat digestion. This supports existing evidence that beans are an economical and sustainable way to reduce CVD risk.

In addition, the team has showed that HHP is a promising green technology for manufacturing beans with a range of functional properties while effectively preserving and/or enhancing the BS-retaining ability of beans. Therefore, HHP has the potential to increase the use of beans as nutritious and cholesterol-lowering ingredients in a range of food formulations, harnessing their health benefits and increasing the number of bean-containing products on the market.

Promoting an overall healthy dietary pattern that includes fibre sources, like legumes, will help people achieve the daily recommended amount for dietary fibre and fulfil other important nutrient requirements while helping to lower the risk of chronic diseases.

Behind the Research

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Research Objectives

Dr Fernández-Fraguas explores the role that the structure of foods plays in determining their potential health benefits.

Detail

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Bio

Dr Cristina Fernández-Fraguas completed a BSc in Chemistry and a MSc in Food Science at the Complutense University of Madrid (Spain), followed by a PhD in Food Science at the Institute of Food Science, Technology and Nutrition (CSIC) and the Complutense University. Before joining Virginia Tech (VT) as Assistant Professor, she was awarded a post-doctoral Marie Sklodowska-Curie fellowship at the Institute of Food Research (current Quadram Institute) in the UK.

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Collaborators

- Prof Sean O'keefe
- Prof Susan Duncan

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VIRGINIA TECH

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Personal Response

What do you plan to study next?

"In order to improve the overall understanding of how legumes improve cholesterol levels, further research needs to address the contribution of phenolic compounds (micronutrients potentially interacting with fibre) to BS sequestering. Furthermore, given that fibre delivers BS to the colon, I am also interested in investigating the role of fibre and BS in shaping the microbial profiles of our gut microbiota. We have demonstrated that food processing can alter the bean matrix and the binding of BS by fibre. Consequently, the way food is processed determines how much BS reach the colon, food fermentability and microbiota composition, all of which affect lipid and cholesterol metabolism. Elucidating the complex crosstalk among fibre fermentation, microbial changes by BS, and the consequences that food processing can have on the gut microbiome-BS axis is key to tune strategies aimed at tackling cholesterol-related disorders."