# Use of Magnetic Resonance Imaging in Food Quality Control: A Review

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## ABSTRACT

Modern challenges of food science require a new understanding of the determinants of food quality and safety. Application of advanced imaging modalities such as magnetic resonance imaging (MRI) has seen impressive successes and fast growth over the past decade. Since MRI does not have any harmful ionizing radiation, it can be considered as a magnificent tool for the quality control of food products. MRI allows the structure of foods to be imaged noninvasively and nondestructively. Magnetic resonance images can present information about several processes and material properties in foods. This review will provide an overview of the most prominent applications of MRI in food research.

## Keywords

Food Quality, Food Technology, Food Analysis, Food Industry, Magnetic Resonance Imaging

## Introduction

With everyday increasing importance of food quality control and wise use of nondestructive methods, corresponding technologies are increasingly being promoted [1]. Traditional assessment procedures such as mechanical or chemical methods are destructive and time-consuming that cannot respond to the contemporary food industry demands. Over the last few decades, image-processing techniques such as magnetic resonance imaging (MRI), optical imaging, ultrasound, computed tomography (CT) and thermal imaging have been utilized for food quality evaluation [2].

MRI is a non-ionizing, non-invasive technology that is widely used in diagnostic radiology. In MR imaging, atomic particles interact with an external magnetic field and emit energy at specific frequencies. Therefore, the emitted signal intensity is representative of the imaged tissue structure [3]. Food science can also benefit from the recent vast developments in MRI. Inspection of food products, from the harvesting to the marketing, can be readily accomplished by MRI. It provides an unrivaled opportunity to better study foods and understand the dynamic interactions that occur during processing and storage [4]. Today, MRI is used at online quality control systems for meat, fruits and vegetables. The applications of MRI in food quality control are described below.

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## Body Composition and Fat Distribution

MRI has been extensively used for assessing meat and meat products [5-8]. The fat content and its distribution are important elements in tastiness, texture and smell of meat product. This is helpful at the online sorting systems [9]. MRI has been employed as an exquisite method for imaging the distribution of muscle and fat [10]; this is done by implementing specific MRI sequences in order to increase the contrast between muscle and fat tissues [11].

Different diffusion coefficients of protons in water and lipid molecules constitute the principles of diffusion-weighted MRI (DW-MRI) for imaging fat distribution. This type of imaging can be used to determine the amount of oil uptake in the meat frying process [12-14]. In another study, MRI and gas chromatography (GC) were used to evaluate the content of fat and visualize its distribution in Atlantic mackerel in two different conditions (most starved and well-fed). For starved fish, fat content (40±23 mg/g) measured by MRI had a correlation with GC (39±16 mg/g). However, no agreement was noticed for well-fed fish. This might be due to the production of non-triglyceride lipids in well-fed fish and different sensitivity of MRI and GC [15]. This survey demonstrated that MRI could depict fat content more accurately than traditional methods. MRI is helpful in determining the distribution, size, volume and shape of the adipose tissues in intact and live fish [16]. Besides fish, composition of other meat types have also been assessed using MRI [17, 18].

## Salt and Water Distribution

MRI can well illustrate salt diffusion and water mobility in meat during brine curing [19-26]. During curing, the meat microstructure greatly changes and the diffusion coefficient increases. The diffusion behavior was explicitly different in various meat tissues. For instance, the diffusion pattern in meat with connective tissue or fat obviously differs from that with pure myofilament. Moreover, MRI is also applied in fish products in order to monitor and optimize brining [27-30]. These studies proved that salt diffusion is higher in the low-density structured tissues.

## Muscle Structure

MRI has the ability to provide structural information about muscle tissue [8, 31-33]. Diffusion tensor imaging (DTI) is a kind of diffusion-weighted MRI that measures diffusion coefficients in at least 6 directions. DTI has the ability to delineate muscle fiber orientation and distribution [34]. It is asserted that DTI can exhibit complex structural information such as fiber type and diameter. These structural details have a correlation with muscle metabolic characteristics [35].

## Cooking Process

MRI can be utilized to monitor the structural events occuring during cooking, proofing of dough and baking in order to enhance the process [36, 37]. During cooking, structural and physical properties of meat would change. Dynamic MRI and thermal simulation were used to monitor deformations and water transfer in meat [20]. MRI was as efficient as traditional destructive methods. These surveys revealed that in contrast with water content, deformation increases with temperature depending on the tissue composition [21]. MRI has also been regarded as a fruitful method for the evaluation of texture and structure of lasagna, pasta, potato and noodles during and after cooking [38-40].

## Freezing Process

The MRI technique can be considered as a useful tool for monitoring the freezing process. In an MRI study, the redistribution of water during drying and freezing of apple tissue was assessed [41]. Some researchers applied MRI to visualize the freezing mechanism of sucrose solution [42]. In a similar study, MRI was used to evaluate ice formation and crystallization of a sucrose solution during the freezing process [43]. The results proved that MRI could appropriately image the behavior of sucrose solutions during freezing.

## Diaries, Cereals and Cookies

MRI has the benefit of being a non-destructive modality for assessing ripening kinetics and quantitative mapping of moisture or fat in dairy products such as cheese. MRI has been proposed to quantify the separation of cream from milk [44, 45].

Water mobility and moisture migration in cereals and cookies such as rice kernel, corn flakes or caramel candies have been investigated by MRI [46, 47]. It has been reported that water mobility changes due to various chemical interactions. MRI can also monitor the diffusion process of lipids in confectionery products like chocolate [48, 49].

## Fruits and Vegetables

There is a plethora of literature reporting the use of MRI as a non-destructive method for the evaluation of agricultural products and postharvest sorting and processing [50, 51]. MRI allows studying soil, root, stem and leaf water content and transport [52].

Internal quality assessment and monitoring of ripening of a wide variety of fruits have been accomplished using MRI: apple, avocado, blueberry, cucumber, durian, kiwifruit, mandarin, mango, melon, nectarine, olive, onion, orange, papaya, pear, peach, pineapple, potato, persimmon, pomegranate, tangerine, tomato, strawberry, melon, watermelon and oil palm fruit [53-58]. MR images could provide useful information on the effect of chitosan on the maturity and conservation of citrus [59]. Usefulness of MRI in distinguishing mealy from fresh fruits such as apple and peach has been confirmed [60]. MRI was utilized to survey the extent of damage caused by low pressure in strawberry [61]. Infestation of apple fruits by the peach fruit moth was studied using MRI, and discrimination between sound and infested fruit was successful [62].

MRI is a technique which can detect and follow up the development of storage disorders over time. It has been applied to recognize core breakdown in pears, worm damage and bruises in different fruits [63, 64]. Some authors investigated water status in kiwi fruits and announced that the water loss rate depends on the initial water status of the kiwi fruit [65].

## Conclusion

MRI is an effective non-invasive technique for quality assessment in a wide variety of food products. In this review, we have discussed recent applications of MRI in the evaluation of body composition and fat distribution, salt and water distribution, muscle structure, cooking and freezing processes, diaries, cereals and cookies, fruits and vegetables. Magnetic resonance imaging is a non-destructive, precise and fast method which has many advantages over the traditional food quality control procedures.

## Conflict of Interest

None declared.

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