

## Evolution of the Grain Dispersal System in Barley and its Origin of Domestication

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### Introduction

The ripening and dispersal of wild barley grains are important for the expansion of its habitat. However, from a human perspective, if grains ripen and drop before harvest, the yield will decrease. A wild barley species was discovered that carries a mutation preventing the grains from dropping, and when planting this mutant, it was found that a large number of grains could be harvested in one operation. The discovery and cultivation of this barley mutant are thought to represent initiation of "the oldest agriculture in the world." However, where and when was barley domesticated?

Carbonized grains of barley were found in earthenware and mud at prehistoric remains in the so-called Fertile Crescent, which includes Israel, Syria, Turkey, Iraq, and Iran. Archaeological prospection revealed that humans collected and ate wild barley at least 23 thousand years ago. Carbon dating estimated that cultivation-type barley was derived from wild barley approximately 10 thousand years ago. However, no clear answers could be obtained to the questions "Where was barley domesticated? Was domestication attempted once or several times?"

For more than 60 years, Okayama University has been studying two genes (*Btr1* and *Btr2*) that are essential for grains of wild barley to drop. These two genes are closely linked with each other.

### Biological Functions of the *Btr1* and *Btr2* Genes in Grain Shedding

When wild barley grains ripen, the rachis nodes are disconnected and the ears drop (Fig. 1). The mechanism underlying this phenomenon has long been believed to be the same as that occurring in the "abscission layer," which is produced when the leaves or fruits of trees ripen and naturally drop. In the abscission layer, cells are naturally separated from each other as an adhesive substance between the cells gradually decomposes; consequently, the leaves and fruits of trees, grains of rice, and parts of plants within the wheat family drop from their main bodies. However, we found that this type of abscission layer is not produced in barley, and instead the cell wall becomes thin and fragile because the second and third layers of the cell wall are not formed at the rachis nodes. We also found that the physical properties of the thin cell wall change as a result of drying, and that it is crushed by wind, gravity, or by animals, consequently causing grains to drop. Therefore, we suggest that the products of these two genes act on the rachis nodes and cause the cell wall to become thin and fragile (Fig. 2).

### Evolution of the *Btr1* and *Btr2* Genes

Our research group isolated these two genes and determined their DNA sequences by combining genomic information with the results of genetic and molecular biology analyses.

*Btr1* and *Btr2* are newly identified genes that encode proteins consisting of 196 and 202 amino acids, respectively. To explore their evolution, these two genes were compared with similar genes in plants of the *Gramineae*, such as barley, wheat, and rice. In barley, two sets of these two genes (a total of four genes) exist. In one set, the base sequence is slightly changed leading to the production of a protein with novel functions, which also contains two transmembrane domains. Furthermore, since wheat possesses a protein that has the same functions, the duplication of these two genes and their functional evolution was unique to plants in the wheat family, and this peculiarity occurred after wheat branched from the *Brachypodium*.

### Origin of Cultivated Barley

More than 60 years ago, Okayama University began to study the *Btr1* and *Btr2* genes, which are involved in the drop of wild barley grains, and found that these genes differed in the varieties of cultivated barley collected from the eastern part of the habitat of wild barley from those collected from the western part of the habitat. In other words, the barley varieties could be roughly classified into two groups. However, when and how the barley we currently use developed remains unknown.

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Fig. 1. Shedding of wild barley grains (Ref. 1)

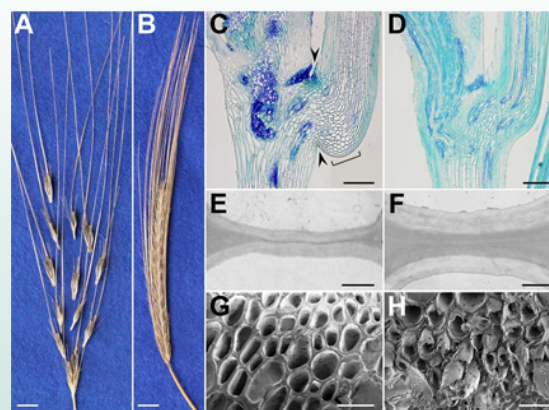


Fig. 2. Spikelet shedding due to the fragile call wall. A, C, E, and G show ripe ears, the cross section of a rachis node, a transmission electron microscope (TEM) image of the same node, and a TEM image of the same node in wild barley, respectively. B, D, F, and H show ripe ears, the cross section of a rachis node, a TEM image of the same node, and a TEM image of the same node in a mutant derived from wild barley, respectively (Ref. 1).

Presently, our study group compared differences in the DNA sequences between these two genes using 529 lines of wild barley and 274 varieties of cultivated barley. As a result, wild barley, which is the ancestor of cultivated barley, was found to have been domesticated twice. In the first domestication in the South Levant (Israel), a mutation occurred, *Btr1* to *btr1* (Fig. 3A). In the second domestication in the North Levant (from northwest Syria to southeast Turkey), another mutation occurred, *Btr2* to *btr2* (Fig. 3B). Varieties of cultivated barley are currently classified into two groups. It was revealed that using these two mutations, "the oldest agriculture in the world" began. Since the feature article (Haberer and Mayer, 2015) is also easy to understand, it is recommended for those who do not have time (Fig. 4).

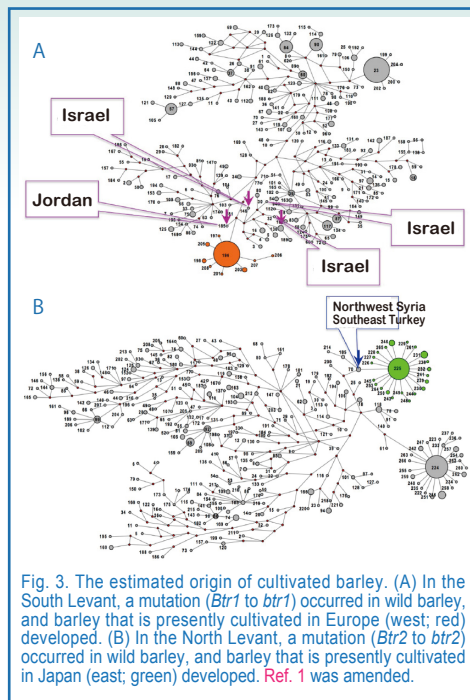


Fig. 3. The estimated origin of cultivated barley. (A) In the South Levant, a mutation (*Btr1* to *btr1*) occurred in wild barley, and barley that is presently cultivated in Europe (west; red) developed. (B) In the North Levant, a mutation (*Btr2* to *btr2*) occurred in wild barley, and barley that is presently cultivated in Japan (east; green) developed. Ref. 1 was amended.

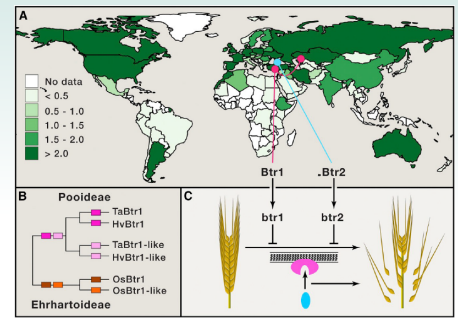


Fig. 4. Barley is the fourth most important food crop in the world. (A) Barley production on a country-by-country basis (2013; unit: 1 million tons; FAOSTAT) (Ref. 1). Wild barley was domesticated in the South Levant due to a mutation in the spikelet indeciduous gene *btr1*, and in the North Levant due to a mutation in the spikelet indeciduous gene *btr2*. (B) The Poideae (including barley) acquired the grain shedding mechanism that is unique to the wheat family following the duplication and functional differentiation of *Btr1*. This evolutionary pattern did not occur in the Ehrhartoideae (including rice), (as shown in the above schematic diagram). Similar gene evolution occurred in *Btr2*. (C) It is proposed that *Btr1* encodes a receptor and that *Btr2* encodes a ligand (Ref. 2).

Ref. 1 Pourkheirandish et al. (2015) Evolution of the grain dispersal system in barley. Cell 162, 527-539.  
 Ref. 2 Haberer and Mayer (2015) Barley: From Brittle to Stable Harvest. Cell 162, 469-471.

## Microsoft Edge, a New Browser

### Browser market share

Which web browser do you use? While the browser that is most commonly used in Japan is Microsoft Internet Explorer (IE), the default browser on Windows computers, Google Chrome has the highest share in most other countries. Even in Japan, the market share of Chrome is growing annually, and the popularity of IE is declining (Fig. 1).

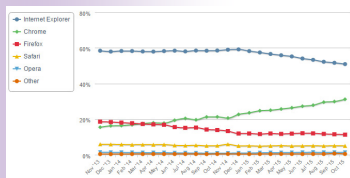


Fig. 1. NetMarketShare: web browser share trend (Oct. 2013 – Oct. 2015)<sup>※1</sup>

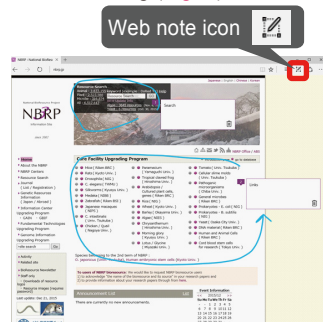


Fig. 2. Example of annotating using Web Note

### A new browser from Microsoft

With the advent of smart devices such as tablets, the way in which we view websites has rapidly diversified. Web technologies are evolving daily, and browsers are being updated to keep pace. Currently, the oldest browser supported by Microsoft is IE7. It was released in 2006 and will continue to be supported until January 2016.<sup>※2</sup> The latest version of IE is IE11, which is supported by Windows 7 or later versions. There is, thus, a total of five supported versions of IE, from IE7 to IE11. Microsoft recently released a new browser called Edge that will eventually replace older browsers. Edge, the default browser on Windows 10, is completely different from IE, and will become the standard browser for future Windows releases.

※1 <http://netmarketshare.com/>  
 ※2 <https://www.microsoft.com/windows/lifecycle/iesupport/>

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### Unique features of the Edge browser

In general, browsers differ only in their appearance, and there are no major differences between IE and Edge in the way contents are displayed; however, there are some new features. In particular, I would like to mention the Web Note feature that allows you to scribble notes on any web page as if you are writing in a notebook. Simply click on the "Web Note" icon located in the upper right-hand corner to begin writing on a web page. You can save an annotated web page by adding it to the bookmark. Previously, you would have had to take a screenshot, and then use another application, such as Microsoft Paint, in order to add annotations. Using Edge and its Web Note feature, there is no need to launch another application. You can also share annotated web pages, or create a how-to page that explains the use of a website (Fig. 2). Why not give it a try?

Additionally, there are other new Edge features, including "Reading Mode," which converts a web page that is cluttered with advertisements, menu bars, and other elements into a simplified page that is optimized for reading the main article, as well as "Ask Cortana" (Fig. 3). Cortana is Microsoft's personal assistant function. By asking Cortana questions, it can display information related to the current web page, including search results and other information, including weather, news, and stock prices, without having to navigate away from the current page (Fig. 4). Cortana is capable of machine learning, and I am excited about how its functions will expand.

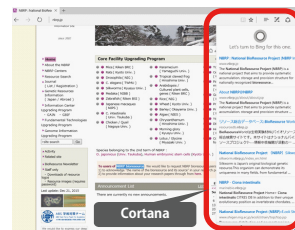


Fig. 3. "Ask Cortana" example: list of bio-resources from an internet search.

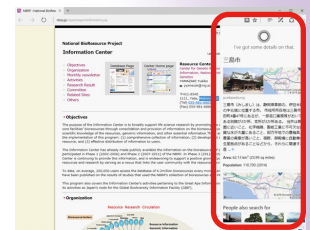


Fig. 4. "Ask Cortana" example: information on Mishima

As described above, Edge is Microsoft's latest browser with new features that are not available in other browsers. All eyes are on the future of browser market share with this new addition.

(Mika Nagahora)

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### BioResource Information

(NBRP) [www.nbrp.jp/](http://www.nbrp.jp/)  
 (SHIGEN) [www.shigen.nig.ac.jp/](http://www.shigen.nig.ac.jp/)  
 (WGR) [www.shigen.nig.ac.jp/wgr/](http://www.shigen.nig.ac.jp/wgr/)  
 (JGR) [www.shigen.nig.ac.jp/wgr/jgr/jgrUrlList.jsp](http://www.shigen.nig.ac.jp/wgr/jgr/jgrUrlList.jsp)

### Editor's Note

The structures of genes that were first identified more than 60 years ago were elucidated by the present genomic analysis, and a new mechanism underlying grain shedding was clarified. Comparison of the base sequences of many wild lines with those of varieties preserved by the Barley and Wild Plant Resource Center, Okayama University, led to the elucidation of the origin of the oldest agriculture in the world. This time, such enormous and dramatic study results were kindly introduced by Professor Komatsuda. I imagine the fertile land of more than 10 thousand years ago, and hope that the earth will be a peaceful and livable place for our contemporaries (Y. Y.).