

REGULAR ARTICLE

Pfeiffer wheat: An old variety with a bright future

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Abstract

Last century, the old winter wheat Pfeiffer was derived from a spelt by breeders in the biodynamic farming movement. The variety has practical significance because of reduced threshing problems. It has historic significance because it is the result of the exercise of an alternative perspective on breeding and heredity. The derivation of this wheat was the result of phenotypic selection of a feral spelt found in Italy in the time period between 1928 and 1940 by a team of breeders working in Germany, Holland and Switzerland. Plants were seeded at different times of the year to induce phenotypic changes; this was coupled with selection pressure for the bread wheat type of ear. Though all plants initially had typical spelt phenotypes (lax heads with brittle rachis and glume enclosed kernels) a few mutations, possessing compact heads and bread wheat heads, were found and selected on all sites and fixed for bread wheat head type on two of the three sites. Proposed explanations for the transformation (outcrossing to a bread wheat, mutation, atavism, or action of a living archetypal agent), are discussed in the light of the available evidence and heredity of domestication events for wheat and maize.

Key words: Wheat, Spelt, Epigenetic, Biodynamic, Domestication

Introduction

Over the last two decades I have had the opportunity to evaluate and select an old hexaploid bread wheat variety called the Pfeiffer wheat, that was derived from a spelt variety called Rome. I received the Pfeiffer wheat from Mac Mead of The Fellowship Community in Spring Valley, New York in 1994. They had obtained it from Erika Sabarth who had selected it in Spring Valley for decades under the direction of Ehrenfried Pfeiffer, a famous pioneer of biodynamic farming in North America. It was grown by Mac Mead for several years before I obtained it. The wheat had a long-term history of having been bred by biodynamic researchers in Europe. After receiving the wheat I grew it and selected it for adaptation to Midwestern conditions. It was grown for three years in conjunction with tests of wheat at Michael Fields Agricultural Institute. Afterwards it was grown independently by myself for multiple years and selected for winter hardiness, foliar disease resistance, and uniform, dark grain color. In one of

the early years of selections harsh winter conditions decimated up to 75% of the stand. The subsequent selections have demonstrated adequate winter hardiness for Wisconsin conditions.

The practical significance of this wheat is that it represents a free-threshing selection from spelt that may combine the nutritional value of spelt with an easy-to-harvest ear form. This is important because it could greatly decrease the costs associated with harvesting and processing spelt seed which is encased in glumes and needs to be milled out of its enclosure. Because pure spelt is a conceptual reality in the marketplace, it is important to know if the variety was derived from an outcross with wheat, or through mutation(s). But there is additional theoretical significance of this wheat in that those who bred it believed it to represent the result of an unusual trans-mutation event. The description they gave of this transformation does not easily fit with current modes of thinking about domestication events. The discrepancies with conventional genetic thinking were not resolved and were forgotten. And finally, the spelt project is one of the first breeding efforts of the biodynamic farming movement and probably helped shape their approach. In the following we will explore the interesting history of how this wheat was developed, discuss what it might be, and examine the biodynamic perspective on breeding in contrast to conventional approaches.

Received 15 October 2013; Revised 25 November 2013; Accepted 27 November 2013; Published Online 01 December 2013

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The biodynamic movement and selection of primitive grasses

The Austrian philosopher Rudolf Steiner (1861-1925) developed a movement called Anthroposophy (Wisdom of Man) that was concerned with what he called a spiritual-scientific approach to life. In a course given in Germany in 1924, he outlined a form of organic farming which was subsequently called the biodynamic agricultural method (Steiner, 1993). Steiner was concerned with a general decline in food quality associated with the introduction of chemical-fertilizers. He indicated that chemical fertilization practices would produce large yields and produce products that were big and attractive in appearance. However, they were increasingly becoming 'stomach filler' with declining taste that did not properly foster human health and development. The decline in soil and crop health and nutritive value of crops (wheat, potatoes, barley, oats, alfalfa, etc.) paralleled the need for ever more new cultivars, a general increase in crop and animal disease, a growing fragility of agricultural systems, and a decline in human health and in the ability for humans to fully manifest their highest intentions in deeds. Steiner stated that by the end of the 20th Century common food products would have degenerated to the extent that they could no longer be useful for human nutrition. He suggested changes in attitudes towards farming, including the principle of forming the farm as a relatively closed, self-sustaining system with respect to manure and fertilizers, the integration of animals, the use of biological preparations as medicines for the earth and crops, and the forming of healthy farm-landscapes, as remedial measures.

He also suggested that his students apply these methods and try to domesticate primitive grasses in order to produce new cultivars for bread production with 'strong seed forces' (Pfeiffer, 1958). As a breeding measure he suggested alternating the planting dates of cereals closer to the summer or closer to the winter to engender beneficial changes in the plant's constitution. Biodynamic breeding efforts began and continue today with a range of domesticated crops.

Materials and Method

Probably the most useful results were obtained by selection from what appeared to be a semi-wild selection of spelt (*Triticum aestivum subsp. spelta*) obtained by another of Steiner's students by the name of Ehrenfried Pfeiffer from the Rome Botanical Garden in 1928 (Riese, 1940). The variety was mistakenly named 'Einkorn' (*Triticum*

monococcum L. *subsp. monococcum*) but was identified as a hexaploid spelt and renamed 'Rome.' Its plants had a facultative growth habit and could be grown both in spring and winter plantings. They produced a fragile rachis, and seed possessed typical spelt-type spikelets with hull enclosed seeds, and with few kernels in each spikelet (see photo 1). Over more than a decade offspring were grown out on several sites on a yearly basis, sometimes with alternating summer and winter or late summer and early winter planting dates. The plants were closely observed and selected for forms similar to bread wheat. The breeders selected for looser glumes, greater numbers of seed in spikelets, and a more stable rachis. Changes in head type in the direction of bread wheat occurred on all sites. The work was disrupted by the Second World War. No numerical analysis of the data is available.



Photo 1. Rome Spelt (taken in 1936).

Results

The overall work on the wheat from 1928 to 1940 in Dornach, Switzerland was reported on by Erika Riese (1940). They continuously planted out the most bread-wheat-like lines from the preceding year. Results with selection varied from year to year. Bread-wheat-like characteristics, such as seed-growing-through-glumes, or more grain/spikelet, manifested in the harvests of 1932, 1933, but in 1934 no changes from the spelt type were apparent. In 1938, ears with grain growing through glumes and condensed club-wheat like ears were harvested. In 1939, no changes from the normal spelt type were apparent. By 1940 continued selection resulted in a plant with ears that appeared to be a transitional state between spelt and wheat with broad, multi-grained spikelets, but the stability of this form remained to be confirmed by further grow-outs by the time of the final report available to us (Riese, 1940).

Voegele (1938) described his experience with the wheat in Pilgrimshain, Schlesien as follows:

“In 1931, I received glume-enclosed spelt seeds from E. Pfeiffer that possessed all the characteristics of spelt (*Triticum spelta*). These grains were derived from four generations of selection from a plant found in Italy which showed little similarity to a domesticated plant. The (*original*) ears and spikelets were unimpressive; the grains were formed but tiny and narrow. E. Pfeiffer began breeding the plant and after three generations derived a plant that was practically indistinguishable from white spelt. The rapid progress suggested that the predecessors of this variety had been cultivated, but the variety had become wild in its environment. In following years I planted this wheat in alternating seedings in either August or December. I obtained seed from these plantings that was identical to the parental plants. In 1934 in the plot that had been seeded in the previous December, a plant was found with five ears that had the appearance of a naked bread wheat (*Triticum vulgare*). I assumed that the plant was derived from a seed which had accidentally been introduced either through inattention or by an animal, and I was prepared to rogue it out. However, the fact that the form of the ear did not resemble any of our local wheat varieties kept me from doing so. Closer observation revealed that the ear was a transitional form between spelt and bread wheat. A strong rachis, holding the spikelets together, was apparent though it was not as strongly expressed or strong as in common bread wheat. The appearance of the glumes resembled spelt. After

that discovery the plant was of course allowed to ripen. I harvested it myself. When rubbing the seeds out, the transitional characteristics became apparent. On the one hand the rachis was not totally established; on the other hand it was difficult to rub the fully ripe and hard grains from the glumes. The elongated kernels resembled spelt.

At the end of September and again at the end of December, two different beds were planted with the offspring of this plant. All the plants emerged. The September seeding tillered strongly before the beginning of winter. The December seeding emerged in February but shortly afterwards was severely damaged by pheasants so that only 13 plants remained. All these plants grew to ripeness. As long as the ears were not visible there was no particular difference between individual plants. I expected that the daughter plants were the same as the parent and the transitional form would manifest again. This expectation was not confirmed. As the ears shot up in July of 1935, the unexpected impression was that every plant had a different type of ear. Any observer that did not know the previous history of the planting would have had to conclude that a mixture of the most different spelt and wheat varieties had been seeded there.

On the one hand, very different ear forms appeared. Next to plants with extremely long and loosely set spikelets on spelt ears with long straw were short, uncommonly compact ears on short straw, which resembled *Triticum compactum*; between these cylindrical ears of all kinds appeared. A greater diversity of form would not have been achieved if each of the planted seeds had derived from a different spelt or wheat variety. Because I harvested the seed from the mother plant myself, had rubbed them from their glumes myself, had kept them under lock up to planting, and then had seeded them myself, it could not be doubted that the resulting plants that produced the chaos of forms were derived from the mother plant.”

I was unable to find a description of the selection history at the Loverendale experimental Farm in Domburg, Holland including methods used or dates of its inception and end. Seed was sent to Martha Kuenzel in Loverendale for selection after being grown in Dornach, (Mos and Heyden, 2006, Schmitt, 2006). Photos exist in the Pfeiffer Archive of the 1934 harvest of the first larger scale planting of the spelt on a very small field, which filled a wagon with bundles, so it could be conjectured that the variety had been under selection and multiplication since at least the fall of 1931. A transitional, spelt/wheat form was found in 1935

and became the basis for fruitful breeding in Switzerland and later in the USA. Seed of 15 breeding lines from this program were apparently given to Dornach for further breeding in 1937, renamed 'Dornach Rome', and planted in September 1937 and subsequent years. Another set of 6 elite lines were obtained by Riese from Holland in 1939 and planted in Switzerland in October, 1940 (Riese, 1940). Photographs of elite lines from Loverendale 1935, 1937, and 1938 were found in the Pfeiffer archive. The transitional form found in 1935 in Holland was described by Riese (1940) as follows:

"In 1935 a spelt plant with a very promising appearance appeared at Loverendale with very solid, beautifully formed, multi-grained spikelets (see photo 2). The seeds of these ears were grown out and all kinds of wheat types and transitional forms appeared in the course of several years (see photos 3-7). This included: pure spelt types with closed spikelets, spelt types with open spikelets, closed spelt types with bread wheat type kernels, condensed club wheat types, in part with empty undeveloped spikelets, and elongated, threshing capable forms with strong rachis and spelt type kernels as well as with bread wheat type kernels. We called the latter ear form 'Theodora.' From the photographic series made available from the Pfeiffer archives it seemed apparent that Theodora had been subsequently re-named 'Reward'.



Photo 2. Loverendale transitional mother plant (1935).

Riese suggested that the cause of the mutation was due to shifting climate and soil types. She described the stages of the manifestation of the mutation as follows:

First stage: On an especially beautiful ear that is well formed from base to tip, one finds the beginnings of a stabile rachis and looser glumes. The grains appear refined and there are three or four grains in each spikelet. **Second stage:** From the offspring of these grains plants appear that have condensed club ears. They can be two rowed but despite that look tousled and angular. The highest and lowest spikelets on these ears are too densely jammed together and are empty of seed. The straw is short; the grains are shriveled, often too light and look like spelt seed. **Third stage:** The ears stretch out again and become longer, with strong rachis and open glumes (the second stage had half open glumes, a partly strong rachis, and are less pleasant to thresh out than totally encased spelt spikelets). They often have empty tip spikelets or fragile parts; there are sometimes spelt-like and sometime wheat-like kernels in such ears. **Fourth and last stage:** An open ear develops with a strong rachis that is threshable. Most of the grain looks like wheat grains; that means smaller, more compact, rounder, flatter in the crease and especially vitreous.

It seems to me that the changes in Rome generally followed these stages but numerous transitional forms could be found. The special characteristic of these plants is that three kinds of forms, that is spelt, cylindrical, and the Theodora type of ears could appear on one and the same plant. In Holland and so far as I know in Pilgrimshain, these transmutations occurred in 1935 and 1936. In Dornach something similar finally appeared in 1939/1940. That needs to be confirmed by results in 1941.

Our spelt mutation was a unique origin and development. Though it was derived in a short period of time, in most cases it did not appear suddenly, but rather the changes occurred gradually, through several growing years, on a single plant often with different transitional stages. The same plant could have both normal and varying ears on its straw.

Privy councilor Bier (1934) observed analogous processes when breeding lupins also under biodynamic conditions and characterized them under the name 'transmutations'. By transmutations are meant changes that suddenly appear within a growth period but at least in part show transitional, or in-between forms, so that the complete, natural working through of the forms can take place over several growing seasons. These

forms are constant in their inheritance, without segregating after Mendelian laws, but they find shape mainly in the course of a few years.



Photo 3. Wheat type 4, Dornach, 1937.

Definite, parallel changes in single plants, so called correlations could be established. Many of these are known from normal cereal breeding with crosses. The most significant were: 1) stronger formation of straw paralleled less tillering. Relatively strong tillering can naturally be achieved by cultural measures such as transplanting and cultivation, but that has nothing to do with inherited characteristics. 2) An ear became multi-kernelled, open in its glumes and strong in rachis, though the full formation of these traits by our 'transmutation' took place over multiple generations. 3) If a condensed, cylindrical ear developed, the straw was also shortened by a shortening of internodes and more strongly formed. There was no correlation between the form of the grain and of the ear. In typical spelt ears with fixed, closed spikelets, it is

possible to occasionally find bread-wheat-like kernels. In typical wheat ears it is possible to find both wheat and spelt-like kernels and transitional forms. It remains to be seen whether or how those forms will change in the future."

Katherine Castelliz (1989) who participated in the project wrote: "When I came on the scene in 1938 there was a variety of different ears, sometimes even on the same plant...Among the variety of forms developed were some stable ones. There was one particularly beautiful one which Ehrenfried Pfeiffer took with him to America. The ear was three to four inches long, had a firm axis and 4-5 grains per spikelet. However, the grains were of the common wheat type whereas the original plant, as well as some of the later derivatives had typical spelt wheat grains. The shape of either of them is very distinct. The grain was readily threshable."



Photo 4. Wheat type 3, Dornach, 1937.



Photo 5. Wheat type 7, Dornach, 1937.

Discussion

Why did the transformation happen? These results can stimulate questions of how the transformation was elicited and what was its basis? Voegelé (1938) suggested four different possibilities.

- 1) The transformation was due to the activity of a creative inner principle or archetype that lives in wheat and is capable of breaking hereditary barriers and transforming one form of the species into another.
- 2) The transformation was due to contamination, especially due to outcrossing of spelt with bread wheat.
- 3) The transmutation was due to a genetic mutation.
- 4) Transformation was due to a throwback to an atavistic form.

There could be various combinations of overlapping truth in explanations between explanation 1, 3, and 4, but it seems as if explanation 2 is true all other proposed

explanations may be false, so we will explore it first.

Outcross

It would be easy to quickly dismiss the results as the result of an outcross. Crosses between European spelt and bread wheat often exhibit a range of ear types including lax spelt type and *compactum* types (Dvorak et al., 2012).



Photo 6. Wheat form 2, 1938.

Though possible, there are several arguments why this explanation is improbable for fitting all of the phenomena. Riese (1940) refers to the gradual, phasic nature of the changes, and also to observing different kinds of heads (spelt, cylindrical, and bread wheat type) on the same plants. As plants were individually transplanted it should have been possible to observe this. She also refers to a lack of Mendelian segregation with the transformation, suggesting that the evolution of form proceeded in a direction without segregation of individual traits.

The transitional forms noted in 1933 in Germany and in 1935 in Holland are similar to descriptions of spelt x bread wheat F1 plants

(Muramatsu, 1963). The variation of many types of ears described in Germany and Holland show a pattern reminiscent of that expected with a segregating F2 population. Voegelé (1938) mention that the forms that appeared in 1934 in his garden had maintained stability for more than four subsequent generations, but that does not mean there was no variation within the forms. Riese (1940) stated that after having received the 15 Lowerendale selections in Switzerland in 1937 she categorized them into 16 types according to their ear type, with one type being a mixture of all forms, but grew only 14 types again in 1937. Photographs 3-7 show ear forms within the different selections from 1937 and 1938. In 1939 she discarded some lines because: "Different types were discarded because they were not pure or not healthy, too unstable, or poor ripening." She only grew 12 types in 1939. Also after having received the second set of (6) breeding lines from Loverendale in 1939, she states that several of them were discarded as being backsliding spelt types.

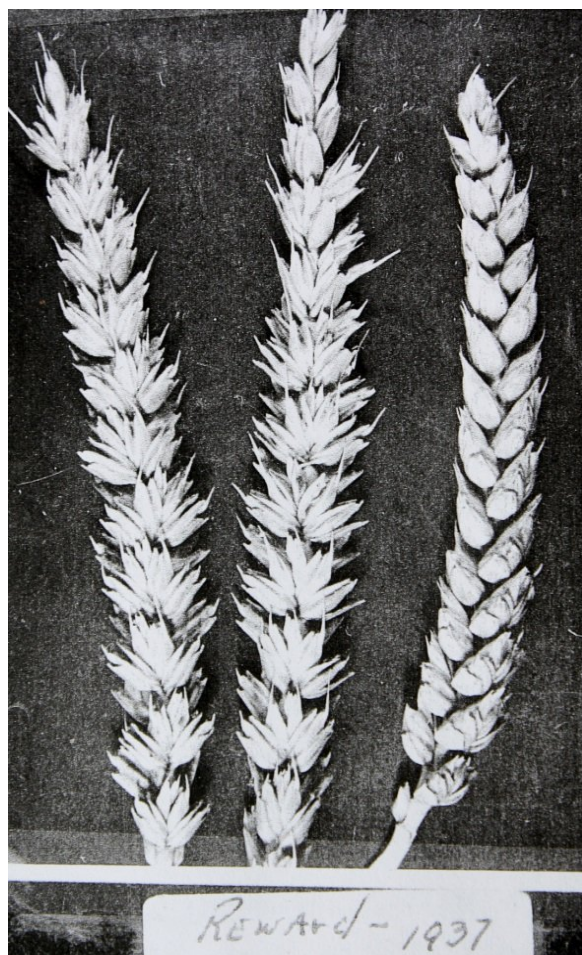


Photo 7. Theodora/Reward ear types, Dornach, 1937.

Boshnakian (1922 and 1923) studied crosses between spelt and bread wheat and linkage between rachis strength and glume tenacity. He also found strong dominance of the spelt ear type in the F2 followed by segregation in the F3 generation for ear density, probably associated with segregation of forms of the C gene. Neither of these segregation patterns were reported by Riese (1940) or Voegelé (1938).

If outcrosses occurred, then when, where, and how often? Descriptions and photographs of the Swiss breeding program suggest that protocol involved plants seeded in the fall being transplanted out into the field in the spring into isolated bird and animal proof cages, possibly to obviate contamination as well as to reduced depredation. Bread wheat was not part of their other plantings. Yet they recorded seeing compactum type heads and soft-glumed phenotypes with variable stability in their evolving set of spelt lines which only gradually became bread-wheat like. Though there were some ears noted already in 1930 with grain growing through glumes, club wheat ear types, combined with weak glumes, appeared first in 1937.

Meanwhile the breeding programs in Germany and Holland had been separate from the Swiss program and operational for several years before transitional forms were observed on each site in 1933 in Germany and 1935 in Holland. If outcrosses are to explain results in Switzerland, Holland and Germany, they would have had to have been separate outcrossing events, taking part in different years.

We do not know if bread wheat was planted near to the spelt plantings in Holland or Germany. But a review of recent field research on outcrossing in wheat (Anon. 2006a) suggests that outcrossing is generally a very seldom event; only up to 1% if plants are spaced approximately 30 cm apart and minimal or non-existent after that. Voegelé (1938) argued that spontaneous European spelt x wheat crosses are either rare or non-existent. Furthermore, on the basis of the appearance of offspring, Voegelé (1938) denied that other wheat cultivars existed in his region that resembled the offspring found in the spelt plantings.

The possibility of outcross, though probably implausible for explaining all the results, cannot be ruled out without further investigation, such as marker selection work on storage proteins in grains. Though there is no source of the original spelt seed to use as a check, other European spelt cultivars

might serve that purpose to test the Pfeiffer wheat that is available today.

Mutation

Several genes are thought to play a role in controlling the stability of the rachis, glume structure and openness in hexaploid wheat. The brittle rachis loci (*Br1*, *Br2*, and *Br3* located on the chromosomes 3D, 3A, and 3B, respectively) have recessive alleles that reduce brittleness. *Tg* (tough glume) located on the short arm of chromosome 2 affects the morphology and hardness of glumes and a recessive allele *tg* conditions soft glumes that allow for free threshing. The *Q* gene, located on the group five chromosome of the AA genome is pleiotropic for domestication traits; it reduces rachis brittleness, loosens glumes, and induces compact, 'square headed', and free-threshing ears (Fans et al., 2013; Simons et al., 2006). The *Q* allele is a hypermorph or more active form of the *q* allele in conveying effects of domestication (Muramatsu, 1963). It differs from *q* by only one amino acid sequence. The *Tg* allele is epistatic to the *Q* allele, inhibiting its action (Fans et al, 2013; Simons et al, 2006). Though *Q* is often cited as a super domestication gene its action is strongly modified by the background it is in. The less active *q* gene is found in European spelt (Luo et al, 2000). When placed in a domesticated wheat background *q* produces a more 'speltoid' ear but does not result in a fully hulled ear and the rachis is not brittle (see figure 1 in Luo et al, 2000). The background heredity of spelt conveys additional primitive characteristics to the ear (Muramatsu, 1963).

If changes in the German and Dutch spelt were due to a single mutation, it must have been a change from *q* to *Q*. However, the *q* gene is thought to have originated only once (Simons et al., 2006). The simple mutation explanation has similar problems for fitting the described phenomena to the outcross explanation. Again, Riese (1940) described gradual, phasic changes, and also observed different kinds of heads (spelt, cylindrical, and bread wheat type) on the same plants. As plants were individually transplanted it should have been possible to observe this. To explain the changes as a single mutation it would be necessary to assume a very variable degree of penetrance of the relevant mutation in individual plants. Voegelé (1938) does not describe phasic changes past the second generation on the bread-wheat-like derivatives. Forms remained stable for four generations after the change occurred; this lack of segregation does not fit a Mendelian explanation of a simple mutation either.

Throw-backs or atavistic changes

Mutations occasionally occur in normal bread wheat changing square headed ears into so called lax speltoid (= spelt like) ears. These mutations are often very unstable and mostly revert to compact ears called 'subcompactoids' (Sanchez-Monges and Mac Key, 1948).

Voegelé (1938) was aware of the spontaneous mutation of wheat to speltoids; in his time this was characterized as a throw-back to atavistic forms. The common theory in his time was that wheat had evolved from spelt (McFadden and Sears, 1948). From Voegelé's perspective it was difficult to look at the transformation of spelt he had experienced as a throw-back; rather he saw it as a repetition of the evolution that had occurred to develop wheat out of spelt.

However, it turns out the evolution of European spelt is different than was previously thought. The current theory, supported by molecular data, is that one of the original parents of spelt was a hulled, tetraploid emmer (*Triticum turgidum* subsp. *dicoccon*) and that the other was free-threshing, bread wheat. Thus wheat did not evolve from spelt, spelt evolved from wheat. This theory is in consonance with archeological findings (Dvorak et al., 2012). It is supported by the fact that most European spelts have an active *Tg* gene in the B genome and an inactive *tg* gene in the D genome (Dvorak et al., 2012). Furthermore, evidence from investigation of the high and low molecular weight glutenins suggests strongly that the free-threshing bread wheat ancestral to European spelts was most probably *Triticum aestivum* subsp. *compactum* or club wheat (Yan et al., 2003). This explains the fact that when European spelt is crossed with bread wheat, the F2 generation mostly segregates out spelt, square-head, and compact ears and why activity at the C gene locus, conditioning compact ears, is present in spelt (Dvorak et al., 2012).

Thus changes observed by the Riese and Voegelé studies (spontaneous shifts to club wheat ears and free threshing structures) could actually be due to a throwback to the parents of European spelt which included club wheat. If so, the main activity of the spelt researchers might have been inducing the shift and stabilizing it. The results of the Swiss researchers suggest that the transformation was latent. The more aggressive alternating planting methods practiced by Voegelé (September and end of December, seed emerging in the spring) might have triggered phasic shifts leading to mutations, changes in epigenetic regulation, or reversions to atavistic patterns (in this case free threshing, compact ears, etc.).

Atavisms, mutations, domestication, and induction of atavistic patterns

In consideration of atavisms as a possible explanation for the results it is useful to discuss domestication phenomena associated with phenotypes of maize. Iltis (1983 and 2006) characterized ear-tassels in maize as a very common atavism, induced in part by environmental factors. Ear tassels are transitional forms between tassel and cob; they are prevalent on primitive maize cultivars and not on modern cultivars. The ear-tassel atavism is a relic of maize's domestication history and particularly the creation of the ear, and it is selected against in corn breeding programs. Iltis described the formation of the ear as a condensation of an axial, primary branch of teosinte, with leaves on the branch becoming husks and tassel flowers changing sexuality from male to female thereby producing naked seed. He described this phenomenon as a 'catastrophic sexual transmutation.' In maize, ear tassels occur not on axial branches, but rather on basal tillers. Convincing information relating domestication to changes in single genes was not available at the time of his initial publication and he related the transmutation to changes in environmental factors inducing shifts that were then subsequently stabilized by human selection.

Since then, a great deal has been discovered (especially by the work of the lab of John Doebley at the University of Wisconsin) about allelic diversity in genes that anchor the differences in floral and fruiting structures between teosinte and maize. The maize allele of the teosinte branched1 gene (*Tb1*) causes stronger apical dominance, inhibits the formation of axial branches, and causes a feminization of tips of branches (ears and ear tassels on tillers) (Doebley et al, 1997; Hubbard et al., 2002). In addition to this, the maize allele of the teosinte glume architecture gene (*Tga1*) induces a loosening of the glume, exposing the seed from its cupulate shell (Dortweiler et al., 1993).

It is interesting that the word '*transmutation*' was used by Voegelé (1938) and Riese (1940) working with spelt, and by Iltis (1983) working with maize for the transformation to domesticated floral structures that transcended static patterns associated with individual genes (trans-mutation). There are common elements associated with domestication of both wheat and maize such as reduced losses of seed and easier harvest, easier access to naked seed, loss of a hulled seed condition, enhanced condensation and re-

arrangement of floral parts, and strengthening of a rachis structure.

Noteworthy are the two opposite directions of the transformations of broadhead and spelt ear types into each other. These are: broad-headed, non-club, bread wheats transforming to lax speltoid and then mostly reverting to 'subcompactoids' (Sanchez-Monges and Mac Key, 1948). Or the gradual progression noted by Riese in Switzerland of lax spelts transforming to compact and then to broad-headed types.

Searching for atavistic patterns may indicate but not necessarily explain domestication events. However, the induction of atavistic growth patterns may be associated with environmental disruptions, and this may explain some of the results achieved in the spelt conversion as mentioned above. This author has noted other atavistic phenomena in his corn breeding, but only following planting under climatic conditions that are non-endemic to the variety and therefore disruptive to plant morphogenetic processes.

The first was the appearance of teosintoid-like axial branches along the main axis of corn stalks when the Peruvian corn races Piricinco (Amazon) and Mochero (Northern Coast) were grown under modified temperate daylight rhythms in Wisconsin in 2009, and also when crosses of adapted cultivars with Mochero were grown in Wisconsin in subsequent years. Botanical descriptions of growth patterns of Piricinco and Mochero landraces in Peru (Grobman et al., 1961) are of early flowering cultivars which only rarely express tillering, and no indication of axial branching at all. The phenomena observed in Wisconsin are strongly reminiscent of the action of the teosinte *tb1* allele on maize (Doebley et al, 1997).

The second atavism is associated with growing Wisconsin corn under tropical daylength conditions. In particular, corn from the Mandaamin Institute breeding program (S2 inbred derivatives between a cross of two populations (LH119 x LH132 and AR16021 x B73) bred in Wisconsin were grown in a winter nursery in Puerto Rico in 2011/2012. Tassels appeared in ear shoots and as well as primitive grassy tillers in some corn plants that were mostly normal in appearance. These growth patterns are similar to the action associated with the teosinte *tb1* allele (Doebley et al., 1997). In 2012, when the next generation of those corn breeding lines was grown in Wisconsin, one of the S3 breeding lines segregated out both normal and what appeared to be pure grassy-tillered phenotypes, with very narrow leaves. The lines

appeared otherwise to be short, otherwise uniform, and inbred so we assumed no recent outcrossing had occurred.

We are not and have not been breeding with teosinte, so these results are probably not due to outcrosses with teosinte, but rather to internal factors and tensions associated with environmental signals.

Transforming activity of a creative plant archetype; a Biodynamic perspective

It is important to clarify what Voegelé (1938) meant with this explanation in which he refers to Goethe's botanical studies and Steiner's interpretation of them (Steiner, 1950). Implicit in Voegelé's exposition is the concept that an inner, essential living principle, evolving archetype or entelechy lives in and encompasses related species and can transform barriers between them. This type lives in the expansion and contraction of growth and forms in the plant and is inwardly perceptible to a schooled power of perceiving and thinking in the sense of Goethe's 'anschauende Urteilskraft' (literally translated as beholding power of judgment) (Steiner, 1950).

Regarding the transformative activity of the archetype, Voegelé refers to the results of August Bier (1934) who observed transformation of phenotypes of lupin species after growing seed which had been dormant for a half century in the soil.

Voegelé (1938), and other biodynamic researchers accepted that genes and chromosomes were structures by which the archetype achieves stability and expression in different forms and species (Pfeiffer, 1958, Engquist, 1970). However genes were not viewed as the source of evolutionary changes. Voegelé cites Bier (1934) regarding explanations based purely on genetic mutations as follows:

"Let us assume such a chromosome mutation was found. This would not really explain anything. The question as to why plants change would simply have become the question as to why do chromosomes change."

Furthermore, Voegelé states: "In the light of extensive knowledge gained in genetics it may be assumed that the mutations described above followed changes in the seeds' chromosomes or genes. But anyone wanting to see such chromosome changes as determining the transformation that follows would only have gone half the distance in his thinking. If I know from earlier observations for example, that ruts going in a particular direction were made by a cart, I cannot

stop at the horse and the cart looking for the factor responsible for those ruts. It should be evident to everyone that I have to go on to the driver who put the horses before that cart and decided which way it should go. Yes, the cart and horses pulling it produced those ruts, but the determining factor was the drivers will."

Voegelé's biodynamic perspective is not opposed to genetic research but rather broadens the perspective of the role of genes in the unfolding of crops and considers them in the context of the active principle working to form the whole plant. Voegelé's perspective is also in consonance with the recent mission statement of the Association of Biodynamic Plant Breeders (Anon. 2006b) which implies recognition and appreciation of the inner principle/archetype active in the crop plant of choice, and perhaps even re-conceiving the work as being a kind of partnership. It seems obvious that the performance of the inner archetype has been conceived of as being the provenance of practical breeding. Whether the plant archetype that lives in the species brings itself to optimal expression within the genetic framework and environment that the breeder has a hand in creating should reveal itself in measurable form, yield and quality characteristics.

Voegelé's perspective on some kind of whole plant dominance over genes may not be empirically foreign to experience gained in practical breeding. In fact, it is a commonly recognized phenomena that whole plant performance often suffers with the introduction of novel single mutations that are introgressed with the intentions to improve a crop. Furthermore, developing 'perceptive judgement' is probably not a foreign concept or capacity to breeding as it was conceived of in the last century. Training the 'breeders eye' or 'gaining a sense of the organism' was a valuable opportunity and the result of constant learning built on observation and spending a lot of time with the species of choice. Of course, such human capacities are inadvertently 'selected against' by modern breeding approaches that confine breeder activity to farm machinery or labs and limit conceptual activities to genetic mechanisms.

Our predominant civilization presently views plants as genetic machinery whose evolution was determined by random generation of mutations pruned down by natural selection. The concept of an inner principle or archetype living in formation, utilizing, and evolving such structures may be heretical or anathematic for many. The conception of crop varieties as 'a technology that yields' (roadside advertisement in the U.S.A. for Pioneer

Hi Bred seed products in 2009), and use of genetic engineering to change organisms by rearranging genes from different species, is the natural outcome of the concept of the reductionist world view. However, this perspective is repugnant to many who sense there is more to an organism than a set of mechanically interacting genes, and view genetic engineering of food as a dangerous perversion.

Though Voegelé's dynamic explanation based on Goethe's findings offers us an alternative vision of plants and their evolution, and it fits many of the phenomena presented, his explanation is probably not conclusive to the wider scientific community based on the evidence that was presented. There are too many open questions that are difficult to answer due to lack of sufficient evidence of the simple facts of the case. In particular: What kind of variation existed after the transformations were achieved? Why were there differences in results between sites? Were the changes associated with outcrosses, mutations or epigenetic shifts or some kind of combination? Did the 'trans-mutational' changes referred to result in the production of stable mutations in chromosomes in the direction of domestication? Were they monogenic, multigenic, or changes in background effects? Were the phenomena a step forward or re-creation of ancestral forms?

Furthermore, as Goethe himself found (Steiner, 1950) it can be difficult to convince people about results of experience/thinking-based perceptive judgment if they are closed from the beginning to the possibility that such capacities can exist.

Conclusion

Clearly the explanations available to us up to now do not bring us to unequivocal decisions as to what happened to the spelt. All-in-all, better documentation of such 'trans-mutational' phenomena are critical before they would be widely accepted. The molecular tools needed for measuring changes in alleles and chromatin exist, but it is a question whether interest and readily accessible phenomena are available.

However it happened, the team of biodynamic breeders succeeded in creating a new wheat variety. Voegelé (1938) states that: "Irrespective of whatever theory we have, the fact exists that Nature, through a generous gesture, succeeded in creating a series of different bread wheat forms from spelt."

The Pfeiffer wheat, descended from the Lowerendale selections of Maria Kuenzel that was discovered 78 years ago, selected by Maria Kuenzel, Erika Riese, Erika Sabarth and myself,

sequentially named Einkorn, Rome, Theodora, Reward, and Pfeiffer, still exists (Photo 7, Photo 8) and may be made available to collaborators for appropriate genetic studies to understand its origin.



Photo 8. Harvesting Pfeiffer wheat in Delavan, Wisconsin, USA, 2012.

Acknowledgements

The author gratefully acknowledges Paul Scharff, Mac Mead, Erika Sabarth, Tybil Miller, and Malcolm Gardner of New York State for help in gathering information on the Pfeiffer wheat. Special thanks are expressed to Mac Mead and Paul Scharff for seed of the Pfeiffer wheat and to Paul Scharff for access to and permission to use the photographs in this paper which are part of the Pfeiffer Archive maintained at the Fellowship Community in Spring Valley, New York, U.S.A.

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