Edward East on the Mendelian Basis of Quantitative Trait Variation

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Studies of Size Inheritance in Nicotiana
Edward M. East
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East’s (1916) analysis of corolla length in Nicotiana longiflora was a capstone study integrating Mendelian genetics with a continuously varying phenotype. Gregor Mendel and Francis Galton produced profound insights into heredity by employing mathematics novel to biology (in Galton’s case, novel to science). Both used Pisum sativum to illustrate different patterns of inheritance. Mendel established his ratios by studying qualitative variants [what Darwin (1859) called “sports”]. Those discrete differences were determined by individual genes, and generally displayed dominance and independent assortment, features atypical of the natural variation that attracted students of hybridization, breeding, and evolution. Mendel’s fundamental discoveries were ignored for decades, at least in part because of their questionable relevance to common phenotypic differences. In contrast, Galton studied the distribution and inheritance of continuous variation using characters such as seed-pod length in P. sativum, and human height. Galton showed that phenotypic variation could often be approximated by Gaussian distributions. Comparing the average phenotypes of offspring with their parents (adjusting, as needed, for sexual dimorphism), Galton discovered “regression toward mediocrity,” namely that offspring are generally less “exceptional” than their parents (i.e., they tend to deviate less from their population means). Mendel struggled to convince himself, and his contemporaries, that he had uncovered general principles, failing miserably with his second, and final, publication (Mendel 1870) on interspecific Hieracium “hybrids” (in fact, produced asexually, Olby 1966, Chap. 4). In contrast, Galton (1889) observed normal distributions and “regression towards mediocrity” everywhere. (Unfortunately, Galton’s misunderstanding of the implications of “regression” led to decades of muddled controversy concerning the efficacy of selection on continuous variation, Provine 1971.)

When Mendel’s principles were rediscovered in 1900, two central problems needed to be resolved: determining the generality of Mendelian inheritance, and understanding its connection to continuous variation. Famously, Morgan began his Drosophila experiments skeptical of Mendelism’s generality (Shine and Wrobel 1976, Chap. 4). One of the great triumphs of early 20th century genetics was reconciling Mendelian genetics with Galton’s “biometrical” observations. Both key elements of the reconciliation, environmental effects and polygenic inheritance, appear in Mendel (1866). In discussing flowering time in P. sativum hybrids, Mendel recognized that hybrids can be intermediate, and that subtle environmental differences, such as planting depth and temperature, can critically affect phenotypes. Considering the inheritance of flower and seed-color differences between Phaseolus nanus and Ph. multiflorus, Mendel also clearly understood that, when multiple loci contribute additively to a trait, a wide range of phenotypes can appear in the F2. Shortly after Mendel’s rediscovery in 1900, Bateson and Saunders (1902) conjectured that polygenic inheritance might explain continuous variation. However, it took about 15 years to accumulate convincing data, and it took Fisher’s (1918) brilliance to develop
the relevant mathematics [following important contributions by Pearson and Yule (Provine 1971)].

A trio of plant geneticists, Johannsen, Nilsson-Ehle, and East, were largely responsible for demonstrating the complementary roles of multiple Mendelian factors plus nongenetic, “environmental,” effects. Wright (1968, Chap. 15) gives a concise and authoritative overview of their experiments. Johannsen (1903, summarized in Yule 1903) demonstrated that average bean weight in highly inbred “pure lines” of Phaseolus vulgaris differed because of hereditary factors, whereas weight differences within pure lines were nonheritable, and did not respond to selection. Working with varieties of hexaploid bread wheat, Nilsson-Ehle (1909) found that the range of kernel colors from dark-red to white was determined by roughly equal and additive effects of alleles at three (presumably homologous) loci. East’s (1916) work expeditiously unified environment effects and polygenic inheritance by examining crosses between inbred lines of Nicotiana longiflora with markedly different corolla lengths. Ignoring his small 1913 samples, East found that the parentals had mean corolla lengths of 40.54 and 93.30 mm, with corresponding variances 3.53 and 5.11 mm². As expected with predominantly additive allele effects, the means of the $F_1$ (63.53 mm) and $F_2$ (68.65 mm) were both close to the parental average (66.92 mm). The $F_1$ showed substantially larger phenotypic variance (8.53 mm²) than the parentals, perhaps suggesting that the parents were not fully homozygous (or that their hybrids were developmentally unstable). However, the 244 $F_2$ showed greatly increased variance (40.52 mm²), but none produced phenotypes recovering the parental means—as expected with segregation and assortment of several relevant loci. With five loci contributing to the parental difference, the frequency of each parental genotype in the $F_2$ would be about $10^{-3}$.

As a graduate student, Sewall Wright realized that data like East’s could be used to estimate $n$, the number of loci contributing to the parental difference. Assuming no linkage, equal and additive allelic effects, with all trait-increasing “+” alleles in one parental line, and all “−” alleles in the other, the “Wright-Castle estimator” (Castle 1921 first published the result without acknowledging his student) is

$$n = \frac{(\bar{P}_1 - \bar{P}_2)^2}{8(V_{F_1} - V_E)}, \tag{1}$$

where the $\bar{P}_i$ indicate parental means, and $V_E$ is an estimate of the nongenetic variance experienced by the $F_2$. Under some (but not all) more realistic conditions, including linkage and unequal allelic effects, Equation (1) underestimates the number of loci responsible for the parental difference (Wright 1968, Chap. 15). If we conservatively estimate $V_E$ as the average of the parental variances, East’s data produce $n = 9.6$. Hence, we expect that at least 10 loci contribute to the corolla length difference between East’s varieties.

For those of us who use East’s data to illustrate the reconciliation of Mendelian and Galtonian approaches to inheritance, it is jarring to recognize that East saw his study as capping a triumph of Mendel over Galton (“...Galtonian regression in the original sense is now entirely discredited...,” p. 174). The data that supposedly contradict Galton result both from genetic differences among $F_2$ families, and the high variance of regression estimates based on relatively few observations, a fact East acknowledges later on the same page. Unfortunately, East’s standing as an eminent Harvard geneticist, and his willingness to make unsubstantiated pronouncements, such as rejecting Galtonian regression, also contributed to his influential role in promoting racial anxiety in the United States eugenics movement (East 1920; Provine 1973, 1986).

**Literature Cited**

Bateson, W., and E. R. Saunders, 1902 The facts of heredity in the light of Mendel’s discovery. Rep. Evol. Comm. Roy. Soc. 1: 126–160.

Castle, W. E., 1921 On a method of estimating the number of genetic factors concerned in cases of blending inheritance. Science 54: 93–96.

Darwin, C., 1859 On the Origin of Species. John Murray, London.

East, E. M., 1916 Studies of size inheritance in Nicotiana. Genetics 1: 164–176.

East, E. M., 1920 Population. Sci. Mon. 10: 603–624.

Fisher, R. A., 1918 The correlation between relatives under the supposition of Mendelian inheritance. Trans. R. Soc. Edinb. 52: 399–433.

Galton, F., 1889 Natural Inheritance. MacMillan, London.

Johannsen, W., 1903 Über Erblichkeit in Populationen und in Reinen Linien. Gustav Fischer, Jena.

Mendel, G., 1866 Verusche ueber Pfalzenhybriden. Verhandlungen des Naturforschenden Vereines in Brunn, Bd. IV fur das Jahr 1865: 3–47 (English translation Available at: http://www.esp.org/foundations/genetics/classical/gm-65.pdf)

Mendel, G., 1870 Über Einige aus Künstlichen Befruchtung Gewonnen Hiracium-Bastarde. Verhandlungen des Naturforschenden Vereines in Brunn, Bd. VIII fur das Jahr 1869: 26–31 (English translation Available at: http://www.esp.org/foundations/genetics/classical/holdings/m/gm-69.pdf)

Nilsson-Ehle, H., 1909 Kreuzungsuntersuchungen an Hafer und Weizen. ser. 2, Vol. 5, Ed. 2. Lunds Universitets Arsskrift, Lund.

Olby, R. C., 1966 Origins of Mendelism. Schocken, New York.

Provine, W. B., 1971 The Origins of Theoretical Population Genetics. University of Chicago Press, Chicago, IL.

Provine, W. B., 1973 Geneticists and the biology of race crossing. Science 182: 790-796.

Provine, W. B., 1986 Geneticists and race. Amer. Zool. 26: 857-887.

Shine, I., and S. Wrobel, 1976 Thomas Hunt Morgan. University Press of Kentucky, Lexington, KY.

Wright, S., 1968 Evolution and the Genetics of Populations. Vol. 1. Genetic and Biometric Foundations. University of Chicago Press, Chicago, IL.

Yule, G. U., 1903 Professor Johannsen’s experiments in heredity. New Phytol. 2: 235–242.

**Further reading in GENETICS**

Crow, J. F., 1993 Francis Galton: count and measure, measure and count. Genetics 135: 1–4.

Crow, J. F., 1998 90 years ago: the beginning of hybrid maize. Genetics 148: 923–928.

Lande, R., 1981 The minimum number of genes contributing to quantitative variation within and among populations. Genetics 99: 541–553.
Nelson, O. E., 1993  A notable triumvirate of maize geneticists. Genetics 135: 937–941.
Weir, J. A., 1994  Harvard, agriculture, and the Bussey Institution. Genetics 136: 1227–1231.

Other GENETICS articles by E. M. East

East, E. M., 1916  Inheritance in crosses between Nicotiana langsdorffii and Nicotiana alata. Genetics 1: 311–333.
East, E. M., 1919a  Studies on self-sterility. III. The relation between self-fertile and self-sterile plants. Genetics 4: 341–345.
East, E. M., 1919b  Studies on self-sterility. IV. Selective fertilization. Genetics 4: 346–355.
East, E. M., 1919c  Studies on self-sterility V. a family of self-sterile plants wholly cross-sterile inter se. Genetics 4: 356–363.
East, E. M., 1921  A study of partial sterility in certain hybrids. Genetics 6: 311–365.
East, E. M., 1927  The inheritance of heterostyle in Lythrum salicaria. Genetics 12: 393–414.
East, E. M., 1932a  Studies on self-sterility. IX. The behavior of crosses between self-sterile and self-fertile plants. Genetics 17: 175–202.
East, E. M., 1932b  Further observations on Lythrum salicaria. Genetics 17: 327–334.
East, E. M., 1933  Genetic observations on the genus Linaria. Genetics 18: 324–328.
East, E. M., 1934  A novel type of hybridity in Fragaria. Genetics 19: 167–174.
East, E. M., 1935a  Genetic reactions in Nicotiana. I. Compatibility. Genetics 20: 403–413.
East, E. M., 1935b  Genetic reactions in Nicotiana. II. Phenotypic reaction patterns. Genetics 20: 414–442.
East, E. M., 1935c  Genetic reactions in Nicotiana. III. Dominance. Genetics 20: 443–451.
East, E. M., 1936  Heterosis. Genetics 21: 375–397.
East, E. M., and D. F. Jones, 1920  Genetic studies on the protein content of maize. Genetics 5: 543–610.
East, E. M., and A. J. Mangelsdorf, 1926  Studies on self-sterility VII. Heredity and selective pollen-tube growth. Genetics 11: 466–481.
East, E. M., and J. B. Park, 1917  Studies on self-sterility I. The behavior of self-sterile plants. Genetics 2: 505–609.
East, E. M., and J. B. Park, 1918  Studies on self-sterility II. Pollen-tube growth. Genetics 3: 353–366.
East, E. M., and S. H. Yarnell, 1929  Studies on self-sterility. VIII. Self-sterility allelomorphs. Genetics 14: 455–487.
Mangelsdorf, A. J., and E. M. East, 1927  Studies on the genetics of Fragaria. Genetics 12: 307–339.