# Changes in Yield Stability: Wheat and Maize in Developing Countries

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## 1. Introduction

This study asks whether the diffusion of modern varieties has affected the yield stability of wheat and maize production in developing countries. This is not a new question. Since at least the 1970s, researchers have asked whether the "improved" crop varieties developed by international research centers might heighten the production risks faced by producers and consumers. Critics have long suggested that modern varieties have the potential to raise the variability of yields, possibly leaving poor consumers and producers worse off than with "safer" traditional varieties.

This study will make use of aggregate data on production and yields to tell a different story. The data suggest strongly that, over the past forty years, there has been a striking decline in the *relative variability* of grain yields in wheat and (to a lesser extent) maize in developing countries. The term "relative variability" refers to the variability of production as a fraction of total output. Another way to say this is that increases in yield *levels* have been greater in magnitude than the corresponding increases in yield *variation*, as measured in several different ways.

How much of this change can be attributed to changes in the genetic resources used by farmers? In other words, how much of the decline in yield variability is due to changes in crop varieties? This is a difficult question, but it is one that has important implications for evaluating the work of national and international agricultural research systems. This paper will argue that research impacts on yield stability are the net effect of many separate research efforts. For example, major breeding efforts have focused on disease and pest resistance and greater adaptation to abiotic stresses. To assess the contribution of research to the reduction in yield variability, this study will compare reductions in yield variability in wheat and maize to those in other crops that have not benefited from international research (i.e., oilseeds). It will also compare trends over time in yield variability with trends in intensification, as measured by irrigation.

The conclusion of the analysis is that there has been a significant and valuable improvement in yield stability. Although much attention has been given to increases attained in yield *levels* of wheat and maize in the developing world, the changes in yield *stability* have been equally remarkable. By reducing the fluctuations in grain yields, researchers have played a vital role in making modern crop technology attractive and accessible to farmers around the globe.

## 2. Defining Yield Variability: Concepts and Measurements

This study focuses on reductions in the relative variability of yield; i.e., variability in relation to mean yields. There is a long literature discussing yield variability, and there are many different definitions and concepts used. (See Cuddy and della Valle 1978.) In some literatures, it is common to focus on *absolute* variability in yields (e.g., the standard deviation of yield, measured in kg/ha). Other studies measure yield variability across locations. In this study, however, the focus is on intertemporal variability of aggregate yields, at the levels of countries or country groups. There are several reasons why this is a relevant measure. One reason is that the variability of aggregate yields has important implications for domestic food markets and food prices. Another reason is that yield stability at the aggregate level incorporates the adoption decisions of many individual farmers. In measuring yield variability at this level, we are effectively considering the impact of research on yield *outcomes*. Research institutions have collectively transformed the portfolio of crop variety choices available at different times and places. The impact of their research is in part measured by the realized performance of this portfolio. Intertemporal yield stability is a measure of portfolio performance.

Unlike measures of variability by variety, it looks at the full range of variety choices available to farmers. Looking at aggregate variability also avoids some of the problems that arise with farm-level measures of yield stability: at the level of the individual farm, all choices of varieties and inputs are endogenous, and so it is difficult to know whether yield variability from one year to the next reflects choices or unanticipated shocks.

Yield variability at the aggregate level is an *outcome*, not a choice variable. It makes sense, then, to treat it as a measure that evolves over time in response to the changing array of varieties made available by research institutions. By making available new varieties, research institutions affect the aggregate yield variability.

Declines in yield variability over time may arise from improved disease or pest resistance within a prevailing group of improved varieties; e.g., the replacement of "susceptible" modern varieties by "resistant" ones. Second, they may arise from the diffusion of multiple varieties that differ in their susceptibilities and resistances; although individual varieties may be no more "resistant" than previous varieties, the aggregate portfolio will generally display lower overall variability than any single variety. Third, the replacement of traditional varieties by higher-yielding varieties that may have higher *absolute* but lower *relative* yield variability will tend to decrease aggregate variability. All of these mechanisms – and perhaps others – appear to be at work in the data.

In discussing changes in yield variability over time, this study uses two primary measures of yield variability. In general, the two measures give comparable results. In some cases, however, they differ. The measures are as follows:

Changes in the Coefficient of Variation of Yields:

One measure of yield variability is the coefficient of variation of yield. This is defined as the standard deviation of yield over some period divided by the mean yield over the same period. Specifically, let $y_{it}$ be the yield realized in region $i$ at date $t$.[1] Consider, say, a ten-year period leading up to date $t$. The average yield for this period is simply $\bar{y}_{it} \equiv \frac{1}{10} \sum_{s=t-9}^{t} y_{is}$ . The intertemporal variance of these yields is given by $s_{it}^2 = \frac{1}{10} \sum_{s=t-9}^{t} \left( y_{is} - \bar{y}_{it} \right)^2$ . The standard deviation of yields is simply the square root of the variance, and is denoted by $s_{it}$ . This measure reflects yield variability over time. Now define the coefficient of variation of yields in region $i$ at date $t$ as $CV_{it} = \frac{s_{it}}{\bar{y}_{it}}$ . This measure will vary across regions and over time.[2]

One disadvantage of the measure is that it does not account for any trend in yields. For instance, suppose yields were to grow at a steady rate $g$ over the ten-year period. The faster the growth rate, the greater would be the dispersion in observed yields over the period, and hence the higher would be the measured $CV$ for the period. Correspondingly, if growth rates were always positive but slowing over time, it would appear that the $CV$

[1] This region-specific yield is simply total production divided by total area harvested. Note that it is not the yield of an "average" or median farm, nor is the regional yield the average of farm-level yields.
[2] Note that this measure is not well suited for sets of numbers with a mean value close to zero. For the current application, however, this is not a concern.

was falling, suggesting a decline in yield variability when the driving force was a declining rate of yield increase.

Percent Deviation from Trend:

An alternative measure of variability is the average percent deviation from trend in yields. This is a measure that explicitly addresses the problem of computing variability in a trending data series. Suppose analysis reveals that growth in yields is occurring at approximately a constant rate *g*, such that $y_t = y_{t-1}(1+g), \forall t$. As is well recognized, we could arrive at an estimate of *g* by regressing the log of yield on a time trend variable. In this case, we could observe, for each date *t*, the actual yield, $y_t$, and compare it to the predicted yield, which might be estimated as $\hat{y}_t \equiv y_0(1+g)^t$. (There are other slightly different ways of estimating predicted yield, using different base years and functional forms.) The percent deviation from trend is thus: $\frac{y_t - \hat{y}_t}{\hat{y}_t} \times 100$. Denote this measure as $\delta_t$. Because these deviations are in percentage terms, they are comparable across time, even in a context of rising yields.

To compare yield fluctuations across time, we could compare the average of these deviations over some number of years. For example, define the five-year average percent deviation from trend at date *t* as: $\Delta_t = \frac{1}{5}\sum_{s=t-4}^{t} \delta_s$. If we found that $\Delta_t$ appeared to be falling through time, we might conclude that yields were growing ever closer to a trend growth rate.

A difficulty with this measure, of course, is that it makes sense only when a strong and relatively constant trend growth rate is present. If growth rates are rising or falling markedly, the deviations from trend growth will be inaccurately estimated, and it may appear that deviations are rising or falling when in fact the trend growth rate is rising or falling. Moreover, if the movements around the trend are sufficiently noisy, then this may not be a very useful measure.

The many different approaches to measurement remind us that there is no single "correct" way of measuring variability, but we can nonetheless gain insights from approaching the data carefully.

Many similar methodological and conceptual questions have been addressed in previous studies of yield variability. An important and comprehensive review is provided by Anderson and Hazell (1989). An analysis similar to this one was conducted by Naylor, Falcon, and Zavaleta (1997), for a period ending in 1994. Other relevant papers include Byerlee and Moya (1993), Singh and Byerlee (1990), and Hazell (1985), among others. This study builds on previous work by taking advantage of the longer time spans available more extensive data and making comparisons between wheat, maize, and other crops, and by controlling to some extent for increased input use.

## 3. Data Sources

This paper makes use of data on crop production, area, and yield taken from online tables made available by the Food and Agriculture Organization of the United Nations (FAO) through its FAOSTAT service. The data used in this paper are those posted at http://apps.fao.org/ as of July 2004. FAOSTAT data are also used for measures of agricultural area under irrigation.

## 4. Analysis: Impact of Research on Yield Variability

Table 1 summarizes changes over time in the *CV* for a number of different regions of the world, for wheat. Table 2 shows the same data for maize. The standard deviation used for each year is the computed standard deviation of yields within each region over the preceding ten-year period.[3] This is divided by the mean yield within each region over the same ten-year period. The *CV* is computed for each year from 1970 to 2003. The values for 1970, 1980, 1990, and 2000 are shown in the table. The table also reports the coefficient on a linear time trend of *CV*. This time trend was estimated for the entire 33 years for which data were available. Both the coefficient and the associated *t*-value are shown in the table. A negative coefficient implies a declining coefficient of variation over time – or, in other words, a reduction in yield variability.

The data suggest that the *CV* for wheat yields in almost all regions fell significantly from 1970 to 2000. For developing countries overall, the *CV* fell from 0.108 in 1970 to 0.055 in 2000. In both Asia and Latin America, the fell rapidly and remarkably. It is evident that the fell in a statistically significant fashion for almost all areas of the developing world, with the exception of Africa, where essentially no sub-region showed strongly significant declines in .

For maize, the picture is less clear. For the developing countries overall, the coefficient of variation fell in a statistically significant manner, from 0.093 in 1970 to 0.056 in 1990. The figure for 2000 was somewhat higher, at 0.073, reflecting a slight rise in the *CV* in the late 1990s, but the figures fell again in 2001-03. The time trend is strongly and significantly negative. The patterns *within* the group of developing countries were far more varied, however. The one region that observed clearly negative time trends

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[3] In other words, the standard deviation used for 1970 is the standard deviation of yields in 1961-70.

in the *CV* was developing Asia, where the *CV* fell from 0.129 in 1970 to 0.062 in 2000. Two other large regions of the developing world actually witnessed significant increases in the *CV* of maize yields: the Near East and Latin America and the Caribbean.

As noted above, however, the changes in the *CV* of wheat and maize yields are not necessarily the most useful measures of yield variability. In particular, changes in the *CV* may be a difficult measure to interpret in a data series that has a strong trend. A different approach is to look at the deviations from trend – in other words, to look at the variability of de-trended yield data. This approach requires fitting a single trend to each data series.[4] For purposes of brevity, the results of this analysis are not presented here. In general terms, however, the data show that deviations from trend yields have been relatively constant in magnitude across region and time. There is some evidence that deviations are persistent: an increase above trend in one year is likely to be followed by another positive deviation in the succeeding year. But there is no strong suggestion for either crop that deviations from trend are becoming larger over time. This measure of variability, like the coefficient of variation, supports the notion that yield increases in wheat and maize have come without any evident increase in the frequency or magnitude of yield shocks. Aggregated across the entire developing world, variability of maize and wheat yields seems to be falling, if anything.

<u>Controlling for Inputs and Other Changes:</u>

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[4] If in fact there is not a single trend, or if the trend is not constant over time, this procedure will result in deviations that show significant trend in themselves. Under such circumstances, the magnitude of the deviations is no longer a good measure of "variability" but rather an indication of the error in fitting the data with a trend.

The decline in variability is consistent with an explanation based on genetic improvements, but it is not in itself evidence that yield variance declined due to the efforts of plant scientists. The intensified use of some inputs, for example, would tend to reduce yield variance: irrigation might reduce crop losses due to drought, and pesticides might tend to reduce crop losses due to insects, fungi, and other biotic pests.

Data on pesticide use are too scanty to make any conclusions about the impact of chemical inputs on yield stability. But irrigation data are generally available. The evidence suggests that increases in irrigated area were too small and too steady to achieve the observed reductions in yield variance. For brevity, these results are not reported here in detail, but there is no obvious relationship between the decline in *CV* and any increase in irrigated area.

<u>Comparative Declines in Variability:</u>

The trend data still do not provide convincing evidence that the declining yield is due to research. Perhaps the true explanation is that weather patterns are growing more favorable or other changes in the agricultural sector are tending to produce this reduction in yield . One further comparison can be drawn by considering the pattern of yield for a different group of crops, which were not the targets of concerted breeding in developing countries: oilseeds. In general, oilseed crops were not within the mandate of international research centers, and relatively little targeted research has focused on these crops in developing countries.

For primary oilcrops, as defined by FAO, the developing countries as a whole actually saw an increase in yield from 1970 to 2000. Some regions, such as sub-Saharan

Africa and South Asia, experienced slight declines in yield variance, but other regions witnessed statistically significant increases in the  of oilcrop yields, including South and Central America and portions of the Near East.

Consider, then, the ratio of the  of wheat yields to the  of oilcrop yields. The changes in this ratio over time represent the changes in yield variance for wheat relative to oilcrops. This measure allows us to factor out any common trend in yield variance that affects an entire region, such as changes in infrastructure or farmer education. It leaves us much closer to being certain that the remaining effects are due to crop-specific changes affecting wheat. Varietal technology would be one likely explanation here, although we cannot reject the possibility of other crop-specific technologies that would reduce wheat variability relative to oilseed variability.

Table 3 shows levels of this ratio by region. For the world as a whole and for developing countries in particular, wheat yield variances fell sharply relative to oilcrop yield variance during the period from 1970-2003. The declines have been particularly large in Latin America and the Caribbean and in Developing Asia. Table 4 reports the results of a regression of the ratio of wheat coefficient of variation to oilseed coefficient of variation on a time trend variable. The table shows that wheat variability has fallen in a statistically significant way, relative to oilseed variation, in most of the regions under consideration. This casts doubt on the hypothesis that declines in wheat yield variability were due primarily to intensification of production systems. Increased use of fertilizers, pesticides, and irrigation should have tended to reduce variability for all crops more or less equally.[5] The same would be true for changes in climate or market conditions.

For maize, the picture is less clear. Table 5 shows the levels of the maize coefficient of variation relative to the oilseed coefficient of variation, for a number of regions and a number of dates. Table 6 shows the trends over time in the ratio, by region. Clearly, the trends for maize are much more ambiguous than for wheat. In developing countries overall, we see a decline in the relative coefficient of variation for maize yields compared to oilseed yields, but there are only a few regions displaying statistically significant negative trends. These results are somewhat unsurprising; they suggest that much of the improvement in crude measures of maize yield variability (as documented above) may in fact be due to factors that are common to the entire production systems. This is consistent with the notion that modern maize varieties were not widely adopted in many regions until recently, and not enough time has passed to observe the effects of the most recent generations of maize technologies as they reach farmers' fields.

## 5. Conclusions

It is difficult to offer any watertight account of declines in yield variability at the aggregate level that can be attributed to research. But the accumulation of evidence suggests that there has been a decline in the variability of wheat yields – and, to a lesser extent, maize yields in the developing world. Although there are not sufficient data to allow for direct statistical tests, it seems possible from the data that the declines in variability have been most pronounced in those areas where the new varieties have spread

[5] To the extent that these inputs are used differentially across crops, this would not be exactly correct. But the general notion should hold: if intensification of production systems had been driving the decline in yield variability, this should have affected both crops similarly.

most. The declines in variability are not simply an artifact of measurement techniques. Nor do they appear to be attributable to changes in irrigation (although it might be possible to test this hypothesis directly) or other changes that affected all crops equally. This gives us reason to believe that there is a real and important effect to be observed. Ongoing work examines this issue in a more formal way, using a richer data set on diffusion of Green Revolution varieties.

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**Table 1.** Coefficient of Variation of Wheat Yields, 10-Year Moving coefficient of variation.

| | 1970 | 1980 | 1990 | 2000 | Time Trend Coefficient | t-stat. |
|---|---|---|---|---|---|---|
| World | 0.109 | 0.074 | 0.087 | 0.045 | -0.0021 | -9.4602 |
| Developing Countries | 0.108 | 0.112 | 0.091 | 0.055 | -0.0023 | -5.3597 |
| Least Developed Countries | 0.071 | 0.136 | 0.032 | 0.073 | -0.0016 | -2.8926 |
| Low-Income Countries | 0.147 | 0.083 | 0.083 | 0.051 | -0.0026 | -7.4609 |
| Low-Income Food Deficit | 0.157 | 0.122 | 0.096 | 0.056 | -0.0035 | -8.4079 |
| Africa Developing | 0.113 | 0.083 | 0.165 | 0.086 | 0.0002 | 0.3826 |
| Latin America & Caribbean | 0.114 | 0.080 | 0.096 | 0.065 | -0.0012 | -2.2755 |
| Asia Developing | 0.139 | 0.126 | 0.092 | 0.060 | -0.0031 | -8.5892 |
| Near East | 0.052 | 0.116 | 0.094 | 0.051 | -0.0009 | -2.1681 |

Source: Author's calculations from FAOSTAT online data, July 2004.

**Table 2.** Coefficient of Variation of Maize Yields, 10-Year Moving coefficient of variation.

| | 1970 | 1980 | 1990 | 2000 | Time Trend Coefficient | t-stat. |
|---|---|---|---|---|---|---|
| World | 0.086 | 0.092 | 0.073 | 0.071 | -0.0010 | -5.1189 |
| Developing Countries | 0.093 | 0.098 | 0.056 | 0.073 | -0.0007 | -3.3391 |
| Least Developed Countries | 0.020 | 0.068 | 0.037 | 0.108 | 0.0016 | 4.1526 |
| Low-Income Countries | 0.036 | 0.064 | 0.060 | 0.059 | 0.0002 | 1.2261 |
| Low-Income Food Deficit | 0.105 | 0.122 | 0.068 | 0.068 | -0.0015 | -6.1331 |
| Africa Developing | 0.049 | 0.066 | 0.058 | 0.078 | 0.0000 | -0.1445 |
| Latin America & Caribbean | 0.069 | 0.076 | 0.029 | 0.103 | 0.0013 | 3.0428 |
| Asia Developing | 0.129 | 0.122 | 0.102 | 0.062 | -0.0016 | -6.4007 |
| Near East | 0.109 | 0.054 | 0.143 | 0.112 | 0.0016 | 3.0295 |

Source: Author's calculations from FAOSTAT online data, July 2004.

**Table 3**. Relative variability of wheat yields to oilseed yields, selected regions, 1961-2000.

| | Wheat Coefficient of Variation Relative to Oilseed Coefficient of Variation | | | |
|---|---|---|---|---|
| | **1961-70** | **1971-80** | **1981-90** | **1991-2000** |
| World | 1.818 | 1.290 | 1.084 | 0.674 |
| Developing Countries | 2.370 | 1.637 | 0.981 | 0.650 |
| Low-Income Countries | 4.644 | 1.653 | 0.788 | 0.810 |
| Least Developed Countries | 2.565 | 2.934 | 0.905 | 2.976 |
| Low-Income Food Deficit | 3.331 | 2.732 | 1.033 | 0.764 |
| Africa Developing | 3.360 | 1.378 | 2.812 | 3.159 |
| Latin America and Caribbean | | | | |
| Asia Developing | 1.673 | 1.579 | 0.868 | 0.573 |
| Near East | 0.727 | 1.120 | 0.864 | 0.660 |

Source: Author's calculation from FAOSTAT online data, July 2004.

**Table 4**. Wheat Coefficient of Variation Relative to Oilseed Coefficient of Variation, Selected Regions, 1970-2003.

| | **Trend** | **Standard Error** | ***t*-statistic** |
|---|---|---|---|
| World | -0.044 | 0.003 | -14.723 |
| Developing Countries | -0.054 | 0.002 | -21.718 |
| Least Developed Countries | 0.001 | 0.018 | 0.029 |
| Low-Income Countries | -0.088 | 0.011 | -7.925 |
| Low-Income Food Deficit | -0.093 | 0.006 | -16.413 |
| Africa Developing | 0.051 | 0.011 | 4.502 |
| Latin America and Caribbean | | | |
| Asia Developing | -0.039 | 0.003 | -14.562 |
| Near East | -0.016 | 0.005 | -3.011 |

Source: Author's calculations based on FAOSTAT online data, July 2004.

**Table 5**. Relative variability of maize yields to oilseed yields, selected regions, 1961-2000.

| | Maize Coefficient of Variation Relative to Oilseed Coefficient of Variation | | | |
|---|---|---|---|---|
| | **1961-70** | **1971-80** | **1981-90** | **1991-2000** |
| World | 1.438 | 1.602 | 0.916 | 1.070 |
| Developing Countries | 2.029 | 1.428 | 0.602 | 0.856 |
| Low-Income Countries | 1.152 | 1.278 | 0.572 | 0.946 |
| Least Developed Countries | 0.712 | 1.459 | 1.044 | 4.391 |
| Low-Income Food Deficit | 2.224 | 2.715 | 0.734 | 0.920 |
| Africa Developing | 1.442 | 1.099 | 0.987 | 2.859 |
| Latin America & Caribbean | | | | |
| Asia Developing | 1.549 | 1.526 | 0.965 | 0.588 |
| Near East | 1.526 | 0.523 | 1.310 | 1.464 |

Source: Author's calculation from FAOSTAT online data, July 2004.

**Table 6.** Trends in Maize Coefficient of Variation Relative to Oilseed Coefficient of Variation, 1960-2000.

| | Trend | SE | t-stat. |
|---|---|---|---|
| World | -0.027 | 0.004 | -6.952 |
| Developing Countries | -0.030 | 0.005 | -6.734 |
| Low-Income Countries | -0.014 | 0.004 | -3.445 |
| Least Developed Countries | 0.090 | 0.014 | 6.324 |
| Low-Income Food Deficit | -0.053 | 0.007 | -7.152 |
| Africa Developing | 0.036 | 0.009 | 4.046 |
| Latin America and Caribbean | | | |
| Asia Developing | -0.022 | 0.003 | -6.308 |
| Near East | 0.013 | 0.005 | 2.445 |

Source: Author's calculation from FAOSTAT online data, July 2004.