# FUNCTIONAL CONSEQUENCES OF MARGINAL MALNUTRITION AMONG AGRICULTURAL WORKERS IN GUATEMALA

## Part I. Physical Work Capacity

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### INTRODUCTION

Little is known about the functional consequences of moderate degrees of undernutrition, especially in economically active populations in developing countries. Yet by far the majority of rural adult populations that suffer from undernutrition do so in mild to marginal degrees. The physical performance of the agricultural labourer plays an important role at both the household and the national level, because in these countries most agricultural activities are highly labour-intensive.

The spectrum of nutritional status goes from severe overnutrition to severe undernutrition. According to the most recent literature (1, 2), the classification can be summarized as follows:

| | |
|---|---|
| Overnutrition | severe<br>mild<br>marginal |
| Optimal | |
| Undernutrition | marginal<br>mild<br>severe |

Marginal malnutrition comprises all subclinical forms of malnutrition, that is, conditions that are thought to be related to nutritional deficiencies but are not identifiable as a nutritional disease. Given this non-specific situation, indicators for diagnosing marginal malnutrition must be associated with indicators of functional capacity; in terms of physical work, an alteration in nutritional status indicators is important only when lower performance in specific functions results (2). Thus, the definition of marginal undernutrition in adult workers cannot rely on estimates of body composition, energy intake, energy expenditure, and/or changes in these indicators alone. The above information must be complemented with functional variables such as work capacity, performance,

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and productivity as they apply to the work tasks and setting within a given cultural behavioural pattern (3).

Viteri (4) showed that poorly nourished Guatemalan men have a lower working capacity and work output because of (a) reduced lean body mass, (b) earlier appearance of oxygen debt, and (c) decreased tolerance to oxygen debt. He also demonstrated that increased protein-energy intake over a long time period in chronically suboptimally nourished men produces a beneficial effect on body composition and physical work capacity. Barac-Nieto et al. (5) demonstrated that maximal oxygen consumption ($\dot{V}O_2$MAX) was lower in malnourished men and that most of the change in $\dot{V}O_2$MAX could be related to differences in muscle cell mass.

This study aims at exploring other approaches to define marginal malnutrition and to ascertain the consequences of marginal malnutrition on work capacity and productivity. In part I, the assessment of nutritional status through factor analysis is described as well as the consequences of marginal malnutrition on submaximal and maximal work capacity. Part II will discuss the consequences for economics and human capital formation.

## METHODS

### Study Settings

The results described in this paper make use of data sets collected during two longitudinal studies—one of workers on a suger-cane plantation and the other of coffee pickers in an agricultural co-operative.

#### *Setting 1*

Workers from two communities on a sugar-cane plantation located in the lowlands of the Pacific coast of Guatemala were included in the first study. The combined population of the two communities was estimated at 1,238 persons in 1973. The median household income in 1974 was US $550 per year, excluding certain income components in kind (food rations, free housing, and medical care). Income from wage labour at the plantation typically constituted 90 per cent of total household income. Approximately half of the population was under 15 years of age. The adult literacy rate was low (37.4 per cent), and only 28.3 per cent of the population over 15 years of age had completed any formal schooling.

The principal work activity of adult males was sugar-cane harvesting during the period from November to June and canefield maintenance and cane planting during the emainder of the year. The workers both cut and loaded cane during the harvest period, organizing themselves in teams of four.

Working hours were decided upon by the workers themselves, who were paid a piece-rate. During the off-harvest season, workers were mostly assigned to weed canefield sections using only a machete. Each worker was assigned daily a pre-measured area of 25 by 25 metres, which he could finish at any speed. Although workers could choose their own working hours, they were seldom assigned more than one task a day, and it was remunerated at a fixed wage rate (6).

#### *Setting 2*

The second study involved workers in a community largely organized as an agricultural co-operative, and also located in the Pacific lowlands. The total population in 1977 was estimated at 1,087 persons. Forty-four per cent of the population was under 15 years of age. The adult literacy rate for females was 36 per cent and for males, 59 per cent. Main sources of household income were (a) sale of agricultural products, (b) wage labour for the co-operative and for employers outside the community, and (c) small trade. Median annual household income in 1977 was estimated at US $449, which includes the monetary equivalent of food production for self-consumption (7).

The main co-operative activity was coffee cultivation, which provided the principal opportunity for wage labour. Coffee-picking was undertaken by men, women, and children during the last four months of the year. The co-operative paid a piece-rate for picked coffee. Workers chose their own work hours. After the coffee harvesting season, the co-operative offered very limited work opportunities. Some workers did find temporary work outside the community.

Ninety-four per cent of the households planted at least one crop of maize a year, 72 per cent planted a bean crop, and 31 per cent cultivated rice. A few households grew fruits such as mangos and avocados, which produced additional fringe income. Crops were cultivated for both sale and self-consumption. Agricultural work activities were at a peak during the second part of the year, when these activities placed competing burdens on the households' time and energies, e.g., coffee-picking and harvesting of maize and rice.

### Subjects

In each study, only permanently employed workers were included. This provided a total sample of 158 sugar-cane cutters and 196 coffee pickers. Subsamples of 78 sugar-cane cutters and 58 coffee pickers were selected at random for in-depth studies. Cases with missing or inconsistent data were eliminated, and the final sample sizes were 58 sugar-cane cutters and 56 coffee pickers.

### Measurements

The data presented in this paper were collected at each site during specific periods. Two different data sets were involved in each case: anthropometry and physical work capacity.

The following anthropometric measurements were taken following recommended procedures (8):
- body weight (beam scales, to nearest 30 g),
- standing height (measuring tape, to nearest 1 mm),
- mid-upper arm circumference (measuring tape, to nearest 1 mm),
- leg (calf) circumference (measuring tape, to nearest 1 mm),
- triceps skinfold (Lange skinfold calliper, to nearest 1 mm),

The staff member involved in taking anthropometric measurements was carefully trained and standardized. To minimize inter-examiner measurement error, the same staff member took the same measurements during all examinations, which took place during the period from May to August 1974 on the sugar-cane plantation, and durir g June 1978 in the co-operative community.

Physical work capacity tests were conducted following standard methods. Subjects arrived at the laboratory after a light breakfast or lunch. A submaximal exercise test was performed with progressively increasing work l ads on a Quinton treadmill (4, 9, 10). Before the test, each subject rested for 20 minutes. During the last 3 minutes of the resting period, the subject's oxygen uptake ($\dot{V}O_2$ ml/min) was determined by the Douglas bag method (9) and by the use of a gas meter (Instrumentation Associates Inc., England) and a Teledyne oxygen analyser, and the heart rate (HR beats/min) was measured with a pair of thoracic electrodes coupled to a physiograph (E. and M. Instrument Co., Inc., Houston, Texas, USA). In the test each work load was performed for 4 minutes, and for each work load the subject's $\dot{V}O_2$ and HR were measured during the last minute. With these data the individual linear regressions were obtained for $\dot{V}O_2$ on HR (11). On the basis of these regression equations, oxygen uptake was calculated at a heart rate of 150 beats per minute ($\dot{V}O_2$ 150), which is a maximum rate normally attained during work by these workers.

Direct determination of the maximal aerobic power in these subjects was not possible. The $\dot{V}O_2$ MAX was estimated by first calculating the maximal heart rate of each individual, using the equation published by Davies (12), and then using the individual regression line and the maximal heart rate to estimate the $\dot{V}O_2$ MAX. A more detailed discussion of these procedures can be found in Maritz et al. (13).

The maximal oxygen consumption ($\dot{V}O_2$ Max) per unit of body weight is a standard international measurement of cardio-respiratory fitness (14). It is the highest level of oxygen intake an individual can attain during physical activity at sea level (15).

### Statistical Analysis

Correlation analysis was used to explore the relationships among the variables (11). Factor analysis using selected anthropometric measurements was employed to generate factors that represent different dimensions of body composition and, therefore, nutritional status (16). Simple and multiple regression analyses (11) were used to test the effect of body composition on physical work capacity. The analyses were run using BMDP (17).

## RESULTS AND DISCUSSION

### Sample Characteristics

The sugar-cane workers and the coffee pickers were similar in age and in physical characteristics (table 1). Compared with well-nourished men, these workers consistently demonstated lower mean values in all the anthropometric measurements that approximated those reported for poorly nourished workers (4, 5). The mean values of weight/height, mid-upper arm circumference, arm muscle circumference, triceps skinfold, and leg circumference suggest that the workers were generally lean and muscular.

The submaximal working capacity ($\dot{V}O_2$ 150) in the group of coffee pickers tended to be higher than in the sugar-cane workers. The maximal work capacity ($\dot{V}O_2$ Max) of the coffee pickers was closer to that reported for the well-nourished males and exceeded it when standardized for body weight. The sugar-cane workers demonstrated a lower physical working capacity than the coffee pickers.

### Nutritional Status

Body composition was used to assess nutritional status. Under field conditions, a reliable measurement of body composition (densitometry) is not possible. Anthropometric measurements can easily be taken, and therefore they are usually used to estimate body fat mass (BFM), muscle mass (MM), and fat-free mass (FFM). However, the commonly applied anthropometric indices and predictive equations published in the literature do not necessarily apply to our population, even though body surface, arm circumference, calf circumference, and the weight/height ratio are highly correlated with fat-free mass and muscle

TABLE 1. Age, Anthropometric Measurements, and Physical Working Capacity of Two Samples of Agricultural Workers and Well-Nourished Men in Guatemala ($\bar{X}$ ± S.E.)

| Variable | Sugar-cane Cutters (n = 58) | Coffee Pickers (n = 56) | Well-Nourished Men* (n = 22) |
|---|---|---|---|
| Age (years) | 35.1 ± 1.2 | 38.1 ± 1.4 | 18.8 ± 0.4 |
| Body weight (kg) | 52.6 ± 0.7 | 54.9 ± 0.8 | 60.8 ± 1.1 |
| Height (cm) | 159.3 ± 0.7 | 163.9 ± 0.9 | 166 ± 1 |
| Weight/height (kg/cm) | 33.0 ± 0.4 | 33.4 ± 0.4 | 36.6 ± 0.6 |
| Mid-upper arm circumference (mm) | 251 ± 2 | 254 ± 2 | 281 ± 3 |
| Leg circumference (mm) | 315 ± 2 | 328 ± 3 | 352 ± 3 |
| Triceps skinfold (mm) | 4.5 ± 0.2 | 4.9 ± 0.2 | 8.7 ± 0.5 |
| Arm muscle circumference (mm) | 236 ± 1.8 | 238 ± 1.7 | 253 ± 3 |
| Body surface ($m^2$) | 1.53 ± 0.01 | 1.58 ± 0.01 | 1.67 ± 0.02 |
| Oxygen uptake at 150 beats/min ($\dot{V}O_2$ 150) (ml/min) | 1,761 ± 38 | 1,968 ± 35 | – |
| Maximal work capacity ($\dot{V}O_2$MAX) (ml/min) | 2,341 ± 58 | 2,685 ± 54 | 2,800 ± 124 |
| $\dot{V}O_2$MAX per kg body weight (ml/kg/min) | 44.5 ± 0.9 | 49.1 ± 0.8 | 46.3 ± 0.8 |

* Ref. 4

TABLE 2. Simple Correlations of Selected Anthropometric Measurements with Body Composition Components Estimated by Densitometry Techniques (n = 67)

| Anthropometric Measurement | Body Composition Indicator | | |
|---|---|---|---|
| | Fat-free mass | Muscle mass | Body fat mass |
| 1. Body surface* | 0.91 | 0.70 | 0.32 |
| 2. Weight/height ratio | 0.89 | 0.59 | 0.41 |
| 3. Mid-upper arm circumference | 0.81 | 0.50 | 0.33 |
| 4. Calf circumference | 0.79 | 0.57 | 0.36 |
| 5. Abdominal skinfolds | 0.28 | –0.04 | 0.48 |
| 6. Extremities skinfolds | 0.32 | 0.37 | 0.39 |

Based on data from ref. 4.
$p < .05$ for all correlations except that of abdominal skinfolds with muscle mass.
* Estimated by the Dubois formula.

mass, and abdominal and extremity skinfolds are correlated with body fat. We have found that the Wilmore (18) equation predicted fat-free mass with a high degree of accuracy and reliability (Díaz et al., manuscript in preparation). However, the data available from our field studies did not allow us to estimate the Wilmore equation. Several anthropometric measurements needed for the Wilmore equation were not taken. Therefore, in order to use anthropometry as a predictor of body composition, we performed factor analyses with the data from the study by Viteri (4) to identify factors that accurately and reliably predict BFM, MM, and FFM.

For this data set, the correlations of selected anthropometric measurements with body composition components are shown in table 2. We tried several combinations of variables, and the results indicated that the following variables should be included in the factor analyses: weight/height, arm muscle circumference, triceps skinfold, and calf circumference. After performing a principal components analysis (16), a minimum Eigenvalue of 0.5 was specified to generate factors that would explain a high percentage of the total variance. The matrices were rotated using the varimax method. The factor analysis was then repeated in each of the two groups of workers. Each factor analysis

TABLE 3. Factor Analyses of Anthropometric Variables of Three Samples of Guatemalan Males (Varimax Rotation Method)

| Anthropometric Variables | "Factor 1" Loadings | | | "Factor 2" Loadings | | |
|---|---|---|---|---|---|---|
| | Pooled data* (n = 67) | Sugar-cane cutters (n = 58) | Coffee pickers (n = 56) | Pooled data* (n = 67) | Sugar-cane cutters (n = 58) | Coffee pickers (n = 56) |
| Weight/height (kg/m) | 0.94 | 0.92 | 0.87 | 0.24 | 0.43 | 0.38 |
| Arm muscle circumference (mm) | 0.94 | 0.87 | 0.89 | –0.03 | 0.07 | –0.02 |
| Triceps skinfold (mm) | 0.13 | 0.19 | 0.12 | 0.99 | 0.98 | 0.99 |
| Calf circumference (mm) | 0.90 | 0.94 | 0.87 | 0.20 | 0.22 | 0.14 |
| Eigenvalue | 2.74 | 2.92 | 2.54 | 0.80 | 0.79 | 0.91 |
| % variation | 69 | 73 | 64 | 20 | 20 | 23 |

* Ref. 4

generated two factors (factors 1 and 2); the results are shown in table 3. Despite differences in time and place, the rotated factor loadings of each factor were quite stable across the three groups.

Other combinations of anthropometric variables using body surface, arm circumference, and calf circumference were tested. None of the results provided factors that were more reliable and/or accurate than factor 1. It explained approximately 69 per cent of the total variation of the original anthropometric variables, and factor 2 about 21 per cent.

Further analysis indicated that the factor scores of the generated factors were correlated with the workers' ages. In order to retain age in the regression analyses, the factor scores for age were adjusted using the following procedures: different age groups were established and the same factor analyses indicated above were performed within each age group. Within each study the factor loadings of the respective anthropometric indicators adjusted for age led to results similar to those generated for the samples as a whole. Thus, since the age-adjusted factor scores showed no significant correlations with the workers' ages, they were then retained in the regression analyses.

In order to investigate the interpretation of the estimated factors, the accuracy and reliability method described by Díaz et al. (manuscript in preparation) was applied using FFM, BFM, and MM as reference criteria. The results for factor 1 are shown in figure 1. Factor 1 was close to being reliable and statistically more accurate in the prediction of FFM than alternative factors. Factor 1 shows a maximum absolute error of estimation of 3.5 kg (9.8 per cent). The stability of the factor loadings across the workers' groups indicates that the accuracy and reliability results from the pooled data (4) can be extrapolated to the other two data sets. On the basis of these results, we decided to proceed with factor 1 as an indicator of FFM. Factor 2 showed a low degree of accuracy and reliability as a predictor of BFM. Nevertheless, we decided to explore its relationship with some of the functional variables.*

Based on the above results, factor analysis of selected anthropometric variables appears to be a promising approach to estimating body composition and, therefore, nutritional status. This finding is important because under field conditions it is not possible to apply reliable and accurate methods (i.e., densitometry and 24-hour urinary creatinine excretion) to determine body composition. On the other hand, the commonly applied anthropometric indexes and predictive equations do not necessarily apply to our population. A combination of selected anthropometric measurements, factor analysis, and the assessment of accuracy and reliability of generated factors appears to be a feasible field methodology to estimate body composition.

## Work Capacity

The effect of the factors on submaximal and maximal work capacity was tested by regression analysis. Table 4 shows the regression analyses performed with factor 1.

* The pooled data reported by Viteri (4) did not have all the anthropometric variables that we wished to explore. We are at present studying the body composition of the sugar-cane cutters, using densitometry and 24-hour urinary creatinine excretion results. We are also collecting anthropometric data in order to find more accurate and reliable factors to predict FFM, MM, and BFM.

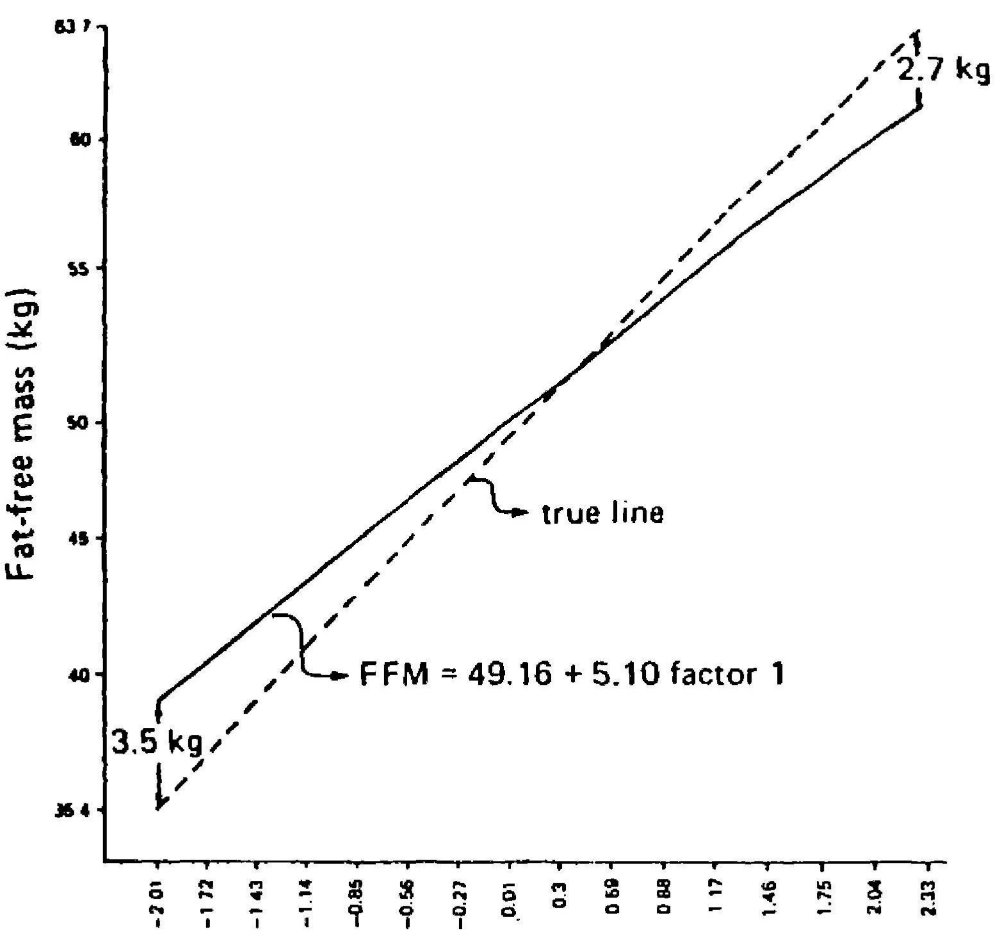


FIG. 1. Accuracy of Factor 1 as a Predictor of Fat-Free mass

Factor 2 did not show a significant effect. There is a significant effect of factor 1 on $\dot{V}O_2$150 and $\dot{V}O_2$MAX. The positive regression coefficients indicate that an increase in FFM is associated with an increase in physical work capacity. Age is negatively associated with the maximal aerobic power of these workers.

The significant effect of fat-free mass on maximal work capacity agrees with previously reported findings among Guatemalan and Colombian workers (4, 5). The quantity and proportion of fat and fat-free mass, including muscle mass, mainly reflect the consequences of nutrition and of activity during the adult life stage. By combining better nutrition with physical activity, muscle mass and thus fat-free mass can be augented in adults; therefore, an effect on physical work capacity can be anticipated.

Factor 1 as an indicator of total fat-free mass, associated with the results of submaximal work, could provide a more complete morphological and functional evaluation (19) of performance and its possible association with nutrition. $\dot{V}O_2$150 is an indicator of fitness that measures the quantity of oxygen ($O_2$) inhaled at a submaximal effort, and therefore it reflects the $O_2$ delivered by heart beat (x 150). Thus, if $O_2$ delivery is not limited by the lungs or blood, it actually measures stroke volume at this submaximal effort. It is still a function of FFM, which means that a greater FFM gives a greater $\dot{V}O_2$150 at a constant fitness level. Fitness can be conceptualized as the adequacy of the stroke volume to satisfy the $O_2$ demand of FFM. Applying this concept to the submaximal effort and without other limiting factors, fitness can be defined as the adequacy of the stroke volume for the FFM at this submaximal level. Therefore, the $\dot{V}O_2$150/FFM can also be a functional indicator. In this sense, it is possible that our labourers will, at the same time, be fit and undernourished. In this case, the above relationship would be high, but it might also be that the marginally undernourished worker is more impaired in fitness than in body composition, in which case the relationship would be low. Our results suggest the latter (20). We speculate that, in a marginally undernourished labourer, the change in fitness following a training period is less than for a well-nourished one; under these circumstances, the change in the relationship of $\dot{V}O_2$150/FFM can be a functional indicator, too.

TABLE 4. Regression Models of Factor 1 and Age on Submaximal and Maximal Work Capacity among Agricultural Workers in Guatemala

| Subjects | Dependent Variables | Independent Variables: Factor 1, $b_1$ | Independent Variables: Age, $b_2$ | $r^2$ | Residual Standard Deviation |
|---|---|---|---|---|---|
| Coffee pickers (n = 56) | $\dot{V}O_2$150 (ml/min) 1,968 | 116* (33) | NS | 0.19 | 239 |
| | $\dot{V}O_2$MAX (ml/min) 3,327 | 184* (41) | –17* (4) | 0.46 | 303 |
| Sugar-cane workers (n = 58) | $\dot{V}O_2$150 (ml/min) 1,761 | 156* (34) | NS | 0.27 | 250 |
| | $\dot{V}O_2$MAX (ml/min) 2,790 | 252* (47) | –13* (5) | 0.39 | 351 |

* $p < .05$
( ) = standard error
NS = not significant

The negative effect of age on $\dot{V}O_2$ MAX agrees with the literature (21, 22). However, the rate of decrease was found to be markedly lower than the rate reported by these researchers. This may be the result of the continuous physical conditioning as part of the men's active life-style. Dehn and Bruce (23) have stated that the decline in maximal oxygen uptake with age is less pronounced in persons who are habitually physically active as compared to inactive persons. The small age effect observed in these workers stresses the importance of their nutritional status (24, 25).

The fact that the FFM has an effect on the physical work capacity of these workers indicates that some of them were marginally to mildly undernourished. The point beyond which FFM does not affect the physical work capacity any more could be the cut-off point to separate the individuals that begin to enter the marginal zone. In order to find this critical point, some non-linear models were estimated ($L_n\ \dot{V}O_2\ Max = 7.70 + 0.10\ L_n$ Factor 1, $r^2 = 0.20$), and even though they were significant ($p < .05$), their explanatory powers were less than the linear models; therefore, it was decided not to speculate about this cut-off point. Also, the need in subsequent analyses to combine the biological functional indicators with economic indices such as productivity for the purpose of defining this critical point has been identified.

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