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THE MANTECA YELLOW BEAN: A GENETIC RESOURCE OF FAST COOKING AND HIGH IRON BIOAVAILABILITY PHENOTYPES FOR THE NEXT GENERATION OF DRY BEANS (*Phaseolus vulgaris* L.)

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Dry beans (*Phaseolus vulgaris* L.) are a nutrient dense food produced globally as a major pulse crop for direct human consumption. Despite being rich in protein and micronutrients, long cooking times limit the use of dry beans worldwide, especially in regions relying on wood and charcoal as the primary sources of fuel for cooking, such as Sub-Sahara Africa and the Caribbean. Coincidently, these same regions also have high densities of women and children at risk for micronutrient deficiencies [1]. There is need for a fast cooking bean, which can positively impact consumers by reducing fuel cost and preparation time, while simultaneously complementing the nutritional quality of house-hold based meals [2].

To help accelerate a reliable increase in dry bean production for Sub-Saharan Africa, the Andean Bean Diversity Panel (ADP; http://arsftfbean.uprm.edu/bean/) was assembled as a genetic resource in the development of fast cooking, nutritional improved, biotic/abiotic resistant varieties. A germplasm screening for atmospheric cooking time (100^{o}C) of over 200 bean accessions from the ADP identified only five fast cooking entries [3]. Two entries were white beans from Burundi (Blanco Fanesquero) and Ecuador (PI527521). Native to Chile, two of the six fast cooking entries were collected from Angola, and had a pale lemon 'Manteca' yellow seed color (Cebo, Mantega Blanca). Traditional knowledge from Chile suggests Manteca yellow beans are low flatulence and easy to digest [4].

Yellow beans of various shades are important in Eastern and Southern Africa. Their popularity has increased in recent years and they often fetch the highest prices at the marketplace. There is evidence to suggest that Manteca yellow beans have a unique nutritional profile when compared to other yellow seed types; with more soluble dietary fiber, less indigestible protein and starch, and are also free of condensed tannins. The hypothesis was tested that this unique composition would also have a positive influence on the bioavailability of iron in an *in vitro* digestion/Caco-2 cell culture bioassay.

The three fast cooking Manteca entries were compared to the white beans (Blanco Fanesquero, PI527521), and to a subset of 11 yellow bean entries selected from ADP that varied in seed type and appearance with geographic origins from North and South America, as well as East and South Africa (Table 1). This model set of 16 entries is identified as the Yellow Bean Panel (YBP). The YBP was planted in a Randomized-Complete-Block Design with 2 field replicates at the Michigan State University, Montcalm Research Farm near Entrican, MI for 2 field seasons (2015, 2016) and evaluated 3 months after harvest. Moisture-equilibrated raw seed (10%) were soaked for 12 hours in distilled water prior to determining the number of minutes to reach 80% cooking time in boiling distilled water using an automated Mattson pin-drop device. Iron concentration and *in vitro* iron bioavailability in cooked seed were measured according to the methods previously describe in Wiesinger et al., 2016 [5].

Table 1 shows the significant variations in cooking times measured in YBP entries, ranging from 16 minutes for Blanco Fanesquero to 69 minutes in Middle American yellow– Amarleo. Values are combined means of field replicates from 2015 and 2016 (entry x year interaction $P = 0.258$). All three Manteca yellow entries had significantly faster cooking times when compared to the other yellow entries of the YBP. Table 1 also shows significant variations in iron concentrations measured in the cooked/lyophilized/milled entries of the YBP ranging from as little as 56 ppm to as high as 70 – 84 ppm in the two Canary seed types and the

Michigan State high yielding yellow breeding line Y11405. There was no relationship between cooking time and the concentration of iron in cooked seed (r = 0.165 P = 0.282).

The y-axis of Figure 1 depicts the significant variations (P < 0.0001) in iron bioavailability measured in cooked/lyophilized/milled entries of the YBC. Iron bioavailability is expressed as the percentage score of Caco-2 cell ferritin formation (ng ferritin / mg total cell protein) that is relative to a high bioavailable iron white navy bean (cv. Merlin) control, which is run with each assay. Figure 1 shows significantly greater iron uptake was observed in all three Manteca entries when compared to the other – especially slower cooking – yellow YBP entries. Figure 1 also illustrates the strong relationship between the cooking time and iron bioavailability scores of the YBP. Although having high iron concentrations, the two Canario entries and Y11405 did not have the highest iron bioavailability (Table 1, Figure 1). These findings add further support to existing research that suggests Manteca seed type has enhanced nutritional and fast cooking properties that can be promoted to populations who rely on beans as a major source of protein and minerals. An opportunity arises for a hybrid between the fast cooking, high iron bioavailability characteristics exhibited by the Manteca yellow bean with the qualities of the high yielding, high iron Y11405 (Figure 1).

1] McLean et al. *Public Health Nutr.* 2009 **12**; 444 2] Rebellow et al. *J. Agric. Food Chem.* 2014 **62**; 7029
3] Cichy et al. *Theor. Appl. Genet.* 2015 **128**; 1555 4] Leakey *Ann. Rpt. Bean Improv. Coop.* 1992 **35**; xiii
5] Wiesinger et al. *J. Agric. Food Chem.* 2016 **64**; 8592

Table 1. Atmospheric cooking times and iron concentrations of entries in the Yellow Bean Panel.

Entry/*Seed Type*	Cooking Time (*min*)[1]	Iron (*ppm*)[2]
Blanco Fanesquero *white*	16^{k}	65^{c}
PI527521 *white*	18^{k}	56^{f}
Ervilha *Manteca*	18^{jk}	61de
Mantega Blanca *Manteca*	19^{jk}	58^{ef}
Cebo *Manteca*	19^{jk}	67^{bc}
Uyole 04 *Yellow*	22^{ij}	60^{e}
Chumbo *Njano*	24^{hi}	62de
Uyole 98 *Yellow*	26^{fgh}	64^{cd}
ACC Y012 *Yellow*	28^{efg}	64^{cde}
Canario, Cela *Canary*	29^{efg}	70^{b}
CDC-Sol *Yellow*	30^{def}	56^{f}
Patron *Yellow*	31de	66^{bcd}
Y11405 *Yellow*	33^{d}	84^{a}
Canario *Canary*	38^{c}	70^{b}
PI527538 *Njano*	39^{c}	66^{bcd}
Amarelo *Dark Yellow*	69^{a}	67^{bc}

[1]Means of two field replicates per entry, field seasons 2015 & 2016. [2]Means of two field replicates per entry, field season 2015. Means sharing the same superscript in each column are not significantly different at $P \leq 0.05$.

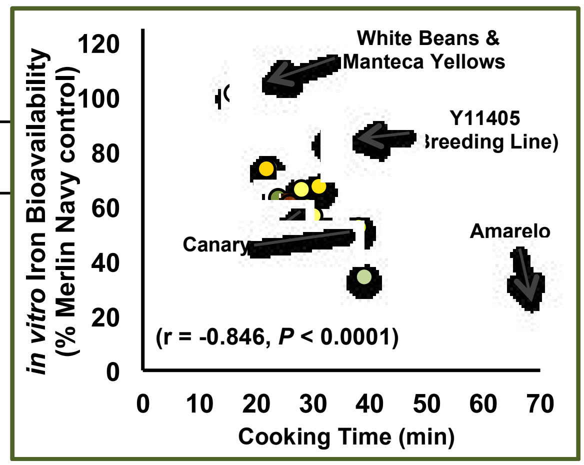

Figure 1. Scatter plot depicting the relationship between the cooking time of the YBP and iron bioavailability. Values are two field replicates per entry for field season 2015.