Abstract: Vitamin A deficiency, the leading cause of childhood blindness in Ethiopia, affects 40% of Ethiopian children and increases childhood mortality by 23%. While government-mandated food fortification in 22 sub-Saharan African nations have cut VAD rates, fortification in Ethiopia remains constricted to a few private companies due largely to technological constraints. In 2011, Ethiopia’s Ministry of Health announced a 4-year plan to mandate fortification of oils and wheat flours. However, fieldwork conducted with stakeholders revealed concern surrounding the importation of mixing equipment, which is costly and prohibitive for small-scale mills distributing to the vulnerable, rural sector. Accordingly, three mixers for factories producing up to 50T oil/day and 100T flour/day were designed and manufactured in Mekelle using locally-purchased stainless steel and aluminum. Experiments using tartrazine and ground capsicum frutescens (Ethiopian chili pepper) as indicators confirmed effectiveness in terms of mixing time and homogenization. While metal-work capabilities are adequate, availability and technical knowledge of stainless steel is limited; thus small facilities can feasibly obtain low-cost aluminum mixers from regional manufacturers while larger companies not requiring automation can purchase stainless steel designs from Addis Ababa. Dosifiers fabricated from stainless steel pose a challenge in all regions, but may be shaped from aluminum.¹

Keywords— food fortification, vitamin A deficiency, mixing processes, local technology, manufacturing, Ethiopia

I. INTRODUCTION

A diet adequate in the essential vitamins and minerals is necessary for proper growth and development. While minute amounts are required, on the order of micrograms to milligrams a day, deficiencies in such micronutrients may have serious consequences for reproduction, immune system response, physical and mental growth and energy metabolism. Micronutrient deficiencies are responsible for an estimated 7.3% of the global burden of disease, with vitamin A and iron deficiencies being among the top ten risk factors [1]. The 2002 World Health Report ranked deficiencies in iodine, iron, vitamin A and zinc among the world’s most serious health risk factors [2].

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Ethiopia is one of the poorest and least developed countries in the world, ranking 173rd out of 187 countries on the 2013 United Nation Programme’s Human Development Report, and a recorded 29.6% of the population lives below the poverty line [3, 4]. 70% of the average rural diet is cereal-based, contributing to a reported 46% of Ethiopians that are undernourished, the second highest rate in sub-Saharan Africa [5]. The four most prevalent forms of malnutrition in Ethiopia are acute and chronic malnutrition, iron deficiency anemia, iodine deficiency disorder, and vitamin A deficiency [6].

A reported 40% of Ethiopian children are severely deficient in vitamin A, contributing to thirty two percent of all childhood deaths and the leading cause of childhood blindness [6-11]. Vitamin A Deficiency (VAD) is responsible for increased instances of night and permanent blindness, ulceration of the cornea, and Protein Energy Malnutrition [12]. A 2010 World Bank study on Ethiopia estimated that improving vitamin A status in deficient populations can reduce young child mortality by 23% and raise the GDP by 1.42% [13]. In an effort to eliminate VAD by 2015, the Ethiopian Federal Ministry of Health (MOH) created the National Nutrition Program in 2008, which outlines food fortification, the addition of vitamins and minerals to processed foods, as a key strategy to eliminate VAD [7].

An 80-year-old practice, food fortification of sugar with vitamin A been used extensively in Latin America since 1970, resulting in the near eradication of VAD in the Western Hemisphere. Currently, national food fortification programs exist in at least 22 sub-Saharan African countries [14]. It is particularly suited to developing countries as the cost of fortified food is less than 2% more than the cost of unfortified food and is shown to be a cheaper and more sustainable alternative to supplementation programs [1].

Edible oil is the number one recommended carrier of vitamin A by the MOH. Refined oils are consumed by 55% of the Ethiopian population in such quantities that an average woman could receive 47% of her recommended nutritional intake of vitamin A and an average child could receive 10-35% from fortified oil. The price to fortify oil is estimated by the MOH at only $0.02/person/year. Wheat flour is another carrier strongly recommended by the MOH. Commercially processed flours are consumed by 28% of Ethiopians and, according to the MOH, will cost $0.10/person/year to fortify [7]. Wheat flour fortification also promises to reduce high rates of folic acid, iron, and zinc deficiencies.

Despite its immense promise, food fortification is rarely used in Ethiopia. The MOH, its subordinate bodies, and its partners in the Ministries of Industry, Trade, and
Commerce are currently involved in the process of passing legislation concerning mandatory fortification of edible oils and wheat flour. Unfortunately, the lack of locally available technology has been identified as a major barrier to the adoption of food fortification. Currently, the necessary technology must be imported from other countries, resulting in a high burden of import duties and transportation costs [1, 7]. To date, little work has been done on utilizing existing manufacturing capabilities and local materials for the creation of such machines. This project explores the possibility of building fortification equipment suitable for small to medium-sized food processing factories using local labor and materials available in local markets.

II. INTERVIEWS WITH STAKEHOLDERS

In order to assess current industrial capabilities as well as attitudes towards fortification, the first two months of the nine month grant period were spent conducting interviews with relevant stakeholders, including oil and flour millers, current fortifiers, NGO’s and ministry officials.

Eight existing flour and oil processing facilities, three that are currently fortifying and five that are not, in both Addis Ababa and the Tigray Region, with capacities ranging from 3-150 metric tons/day of flour and 0.5 – 50 metric tons/day of oil were toured and general managers were interviewed. Larger factories expressed an interest in diversifying their products with fortified goods, while smaller factories had little to no knowledge concerning fortification principles or practices. All processors listed start-up capital costs as a main barrier to adoption of fortification practices, particularly with respect to affordable fortification equipment and laboratory methods of quality assurance. Lack of adequate local fortification equipment was particularly worrisome for small hammer mills distributing to the more vulnerable, rural sector, as importation of fortification equipment proved a larger obstacle. Several companies also noted low public demand for or knowledge of fortified products as a deterrent.

The Ethiopian government dictates the distribution as well as the buying and selling price of all subsidized wheat and wheat flour, respectively, so no wheat flour factory expressed a desire to fortify as there is currently no monetary incentive to do so. The only exception among those interviewed was Lemlem Flour Factory, who hoped to fortify wheat products (i.e. biscuits, pasta) in the future, as these products can be sold at market value to their choice of retailers. Inconsistent wheat supply, rising wheat prices, and high rates of aflotoxin in local wheat also worried wheat millers, most of whom rely, at least partially, on government subsidized wheat imported from India or other nations.

Of the companies specializing in producing fortified

Figure 1. Simplified diagrams of wheat milling (A) and oil refining (B) introducing fortification.
products (Faffa Foods PLC, Health Care Food Manufacturers, and Hilina Enriched Foods), all were using imported fortification equipment, sent samples abroad for nutritional analysis due to lack of complete laboratory equipment, and relied on international relief agencies such as UNICEF or the UN World Food Program for distribution.

Government officials interviewed included those at the Ministry of Health and its legislative and research branches of Food, Medicine and Health Care Administration and Control Authority (FMHACA) and the Health and Nutrition Research Institute (EHNRI), respectively, and the Ministry of Industry. Government officials plan to implement a pilot version of the mandatory fortification program for select oil and wheat millers in September 2014, but expressed concerns about generating enough funds for the program to help private companies cover the start-up capital costs and to provide training workshops and materials for food processors.

NGO’s and development groups interviewed included the Global Alliance for Improved Nutrition (GAIN), Maternal and Newborn Health in Ethiopia Partnership (MANHEP), the Micronutrient Initiative (MI), TechnoServe, and USAID. Such agencies see their role as assisting with funds, convening conferences, providing technical recommendations and disseminating educational materials. Many currently provide support to the national supplementation program, which provides vitamin A, folic acid, and zinc supplements through the Health Extension Worker Program that trains and staffs two female health care providers per kebelle [8, 15].

Based on input from stakeholders, the focus of the project was confirmed as designing and manufacturing local, small-scale pilot versions of fortification equipment in order to lower capital costs and increase access for small flour and oil millers. Fortification equipment includes dosifiers for measured, continuous addition of vitamins to the food matrix, and mixers for homogenization of the vitamins and the food matrix. Figure 1 demonstrates the integration of such equipment into the flour and oil refining processes.

III. MATERIALS AND METHODS

A multidisciplinary team of mechanical engineers and anthropologists was created to provide input regarding the capabilities of local metal workshops as well as the social fabric. Based on their input as well as the equipment currently used in Ethiopian factories, four designs were chosen for local manufacturing and experimentation: 1) electric vertical agitation tank for solid-liquid mixing of powdered vitamin premix with oil, 2) electric horizontal mixer for viscous solid-liquid mixing of premix and flour with water for pasta and biscuit factories, 3) manually operated V-shaped tumbler for mixing of premix and dry flour, and 4) screw feeder for continuous metering of the vitamin pre-mix.

Mekelle, the capital of the northern Tigray region, was chosen as the site of manufacture because it is less industrialized than the capital, Addis Ababa, and thus its manufacturing capabilities are more reflective of the entire country; the technology developed in Mekelle is therefore more reproducible in the regional states with similar technological constraints. Further, with a population of about 200,000, both rural and urban populations live in close proximity so that both groups can have access to factory-produced foods [16]. The Tigray people consume more wheat as a percentage of their diet (13.1%) than any other region, and there are many wheat mills across the region [17].

All equipment was manufactured at Mebratu Araya and His Sons’ Engineering in Mekelle, Ethiopia, with the help of Brothers’ Engineering. Both workshops are two of the larger in Mekelle, with about 25 employees and specialized division of labor.

All stainless steel (304 grade) and aluminum sheet metals (1mm thick stainless steel, 2.5 mm thick aluminum) and pipes (25 mm diameter, 304 stainless steel) used for construction were purchased from Vonall Com PLC in Addis Ababa. The motor and inverter were purchased from Jimma Enterprises in Addis Ababa. Welding rods, valves, molded aluminum for pulleys, bearings, and metal for stands were

Figure 2. Dimensional (a), graphic (b), and as-built (c) views of vertical agitator for oil-vitamin A mixing
purchased from sellers in Mekelle.

1) Vertical Agitation Tank

A 50 liter vertical agitation tank with a four blade, 45° pitched-blade impeller was designed according to the parameters shown in Figure 2. The tank body was constructed from 1mm 304 stainless steel sheet metal, while the impeller blades were formed from a 3 mm thick piece of stainless steel. The agitator shaft was made from the stainless steel pipe. The agitator blades were directly welded to the shaft due to limited supply of food grade bolts and connector material. The rounded shape of the tank’s bottom was difficult to attain, but achieved by cutting triangular sections from a flat circle with an electric hand saw and welding the cut edges together. The support stand for the motor and motor drive was made from angle iron metal. The pulleys for the motor and agitator were carved from a cylindrical bar of molded aluminum using a lathe machine.

2) Horizontal Agitation Tank

A 50 L horizontal agitation tank was designed according to the model shown in Figure 3. The design was based off similar equipment in use for pasta enrichment at Faffa Foods, PLC in Addis Ababa and LemLem Flour Factory in Mekelle. For the purposes of exploring properties of different food grade metals, the tank body was constructed from aluminum sheet metal. The agitator shaft and blades were produced from the stainless steel pipe. The shape of the agitator blades was produced by cutting 12 inch segments of the 25 mm stainless steel pipe, and cutting each side at tapered angles using an electric hand saw, where the cuts began 2 inches up the length of the pipe. The cut edges and top were welded shut and the whole blade was lightly pressed to flatten. A small semi-circle was shaved into the bottom of the blade for a snugger direct weld to the agitator shaft.

3) Manual V-Mixer

The manually operated V-shaped tumbler shown in Figure 4 was designed with small flour factories in mind. Aluminum was therefore chosen for the vessel body, being cheaper, more readily available, and lightweight. For strength, the rotating bar was made from the same stainless steel pipe. The as-built mixer is capable of holding around 5 kg of flour at 40% loading, but can be scaled up and automated for larger mills.

4) Screw Feeder

After discussions with metal workshops in both Mekelle and Addis Ababa, the dosifier was not built, as it was deemed too challenging to fabricate from stainless steel. Technicians

Figure 3. Dimensional (a), graphic (b) and as-built (c) views of horizontal agitator for flour-water-vitamin mixing. Numbers listed are in millimeters.

Figure 4. Dimensional (a), graphic (b), and as-built (c) views of manual V-Mixer for flour-vitamin mixing.
indicated that they could achieve the screw shape by shaving a bar of aluminum using a lathe, but stainless steel is preferable for feeder design.

A less precise feeder consisting of small cups attached to a rotating wheel was considered and deemed feasible to manufacture, but was not built due to time constraints. Such a feeder would be useful for factories desiring continuous flow of flour or oil through a mixing tank.

B. Laboratory Tests

Each of the three built vessels was tested for mixing time and ability to achieve a homogenous mixture using a representative “food matrix” and “mixing indicator”. Samples were taken from each mixer at set time intervals (or turns) and the concentration of the mixing indicator was analyzed quantitatively using UV-VIS spectroscopy (Shimadzu, UV mini-1240) or semi-quantitatively. After mixing was deemed complete, aliquots were drawn from several areas around the mixer and analyzed to ensure uniformity.

For the vertical oil mixing tank, about 7.5 mL Yellow Food Dye #5 (tartrazine; NATCO Foods Ltd., Buckingham, UK) was added to 50 L water. The concentration of the dye was measured spectrophotometrically at 440 nm.

For flour mixing, ground *capsicum frutescens* (Ethiopian red chili pepper, known locally as berberé) was used as an indicator with wheat flour (Huda Flour Factory, Mekelle Ethiopia) as the food matrix. The peppers were obtained whole from the open air market in Mekelle and ground to a powder using a mechanical grinder. 5g of the mixed flour-berberé sample were placed into a 25 mL centrifuge tube (Micron Int., Addis Ababa, Ethiopia) and 20 mL of pure ethanol was added (Sheba Pharmaceuticals PLC, Addis Ababa, Ethiopia). The flour was allowed to settle, and the concentration of the berberé was determined semi-quantitatively by comparison to a set of known standards with an accuracy of ±0.1mg/g. Spectrophotometric measurements of the ground berberé in acetone at 460 nm as suggested by [18] and [19] confirmed that the red color increases linearly with berberé concentration.

IV. OBSERVATIONS AND RESULTS

A. Manufacturing Constraints

1) Food-Grade Metals

To the authors’ knowledge, there is only one wholesaler of stainless steel in Ethiopia, located in Addis Ababa. Aluminum wholesalers are more common, but generally sell for the purposes of building windows, doors, or other home appliances. The thickest sheet of aluminum metal available in Mekelle is 1.25 mm (*Yared Building Materials Shop*). Shown in Figure 6, molding molten aluminum into shapes less than ca 0.25 m³ is a common craft in Mekelle.

As is typical of most metal workshops in Ethiopia, the manufacturers hired for this project are skilled in metals such as iron and steel. Brothers’ Engineering specializes in repairing heavy machinery while Mebratu Araya and Sons’ manufacture many of its products for the Ministry of Agriculture, including beehives, treadle pumps, or seed planters. The manufacturers were unfamiliar with food grade metals, and improper treatment of the stainless steel along weld lines resulted in rusting, presumably due to the disruption of the passivation process by the dusty environment. To the authors’ knowledge, Brothers’ Engineering is the only workshop in Mekelle capable of welding aluminum.
2) Technical Capabilities

The only heavy machinery used in manufacturing the three mixers were machines for cutting and bending, and a lathe machine. An automatic cutting machine and the lathe machine was used to make the initial cuts in the sheet metal and stainless steel pipe, respectively, but hand tools were used thereafter for cutting and smoothing. However, what the manufacturers lacked in technical tools, they made up for in creativity and resourcefulness. They often experimented with achieving proper shapes first through paper models or scraps of metal, using different techniques to see which method was easiest and most effective.

3) Costs

As seen in Table 1, while labor costs were relatively low (4,000 ETB/$205 USD for horizontal tank; 5,000 ETB/$256 USD for vertical tank), motors purchased locally are imported, usually from China, and come no smaller than 0.75 HP, making the cost of electrical agitation artificially high for small factories with low power needs. Welding electrodes contributed to a large portion of the budget, as welding costs were nearly equivalent to the cost of the metal. However, overall, local designs still offer much reduced costs and lower shipping fees at the expense of greater sophistication.

4) Worker Safety

Worker safety was identified as an area needing improvement for local workshops. Protective glasses were provided for the workers but rarely worn when working with heavy machinery. Although the manufacturers owned a welding mask, the preferred protective gear for welding were dark sunglasses and a cloth wrapped around the face with cut-out holes for eyes, which was worn intermittently. Workers wore no gloves for protection against weld burns.

If workers are to produce stainless steel designs, it is imperative that safety standards improve, as common chemicals for promoting passivation and cleaning (e.g. nitric, citric, hydrofluoric and hydrochloric acid) are dangerous or corrosive and must be handled with extreme caution.

B. Mixer Effectiveness

The vertical agitation tank for oil mixing showed a good mixing profile with testing rpm’s of 100, 200, 300 rpm reaching equilibrium after about 60 seconds (Figure 7). Homogeneity tests showed a homogenous mixture with only 1.67% variation (Table 2).

Tests from the V Mixer showed that ideal loading was no greater than 40%, and the mixture reached equilibrium after about 35 turns (Figure 8). Variation in the mixture was minimized when the berberé and the flour were added simultaneously or deliberately placed towards the middle of the V, or when flour loading was minimized. It is suspected that difficulty polishing the inside of the V-mixer resulted in deviations from homogeneity, as it caused the flour to stick in some locations. There was also some leaking of the flour around the lids. The leaking was greater on the leg designated position [-1], which could explain the disparity in berberé

![Figure 7. Mixing time profile for vertical agitation tank.](image)

![Table 1. Cost summary from local manufacture of mixers](table)

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity Used</th>
<th>Price (ETB)</th>
<th>Price (USD)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>SS sheet</td>
<td>1 sheet, 1mm x 1m x 2m</td>
<td>3,500</td>
<td>179.73</td>
</tr>
<tr>
<td>Al Sheet</td>
<td>1 sheet, 2.5mm x 1.2m x 2.5m</td>
<td>2,300</td>
<td>118.11</td>
</tr>
<tr>
<td>SS pipe</td>
<td>1 pipe, 25mm diam, 5.8m length</td>
<td>2,500</td>
<td>128.38</td>
</tr>
<tr>
<td>SS electrodes</td>
<td>110 sticks</td>
<td>3,300</td>
<td>169.46</td>
</tr>
<tr>
<td>Al electrodes</td>
<td>90 sticks</td>
<td>2,300</td>
<td>118.11</td>
</tr>
<tr>
<td>Motor</td>
<td>1 motor, 0.75 HP</td>
<td>3,100</td>
<td>159.19</td>
</tr>
<tr>
<td>Inverter</td>
<td>1 inverter, 1.5 HP</td>
<td>10,600</td>
<td>544.33</td>
</tr>
<tr>
<td>Labor</td>
<td>For all three mixers plus stands (material incl.)</td>
<td>9,000</td>
<td>462.17</td>
</tr>
<tr>
<td>Accessories</td>
<td>6 bearings, 1 valve, 4 pulleys</td>
<td>1,800</td>
<td>92.43</td>
</tr>
</tbody>
</table>

*Conversion rate accurate as of May 7, 2014.
concentration between the two legs (Figure 9). As is recommended for most tumblers, any clumps in the mixing media should be broken up before mixing. Adjustments to the design would include tighter fitting lids, such as screw caps or with rubber seals.

The horizontal agitator proved to be ineffective at mixing dry flour, but created a homogeneous mixture of wet flour and berberé for pasta or bread applications. However, the high viscosity of the flour-water mixture created a power demand too high for our motor, and exact results were not obtained.

C. Information Sharing

Two technical manuals, one for oil and one for flour, were produced as part of this study and disseminated to government officials responsible for legislating and initiating the fortification program, NGO’s involved in program training and funding, and oil and wheat processors that will soon be mandated to fortify their food. Among other considerations, the manual included recommendations for building fortification equipment in country.

V. Conclusions

Local production of food grade fortification equipment will lower the initial capital costs of food fortification and enable more factories to participate in the newly mandated fortification program, simultaneously reducing rates of vitamin A and other micronutrient deficiencies in both rural and urban populations and promoting the local manufacturing sector. This project proved that it is possible to manufacture such mixers/blenders; however, low availability and knowledge of food grade metals and lack of local automation devices (i.e. PID controllers, etc.) pose major challenges.

It is concluded that small factories, defined as those producing <50T flour/day or <20 T oil/day, can feasibly use aluminum-built designs constructed in the regions. However, it is recommended that even small oil factories purchase stainless steel designs as improper polishing of the aluminum surface may inhibit thorough cleaning of the machine. Medium sized factories, defined as those producing 50-100 T flour/day or 20-50 T oil/day, may require stainless steel designs that can be manufactured in Addis Ababa. Smaller regional manufacturers have the capability to work with stainless steel, but first must be trained in proper welding and treatment techniques to avoid rusting of the steel. Large companies with capacities above those aforementioned may retrofit local designs with imported automatic controls, but will likely achieve better results by importing the entire set-up. Stainless steel screw feeders are difficult to make in all regions; aluminum screws are possible to manufacture through lathe machines, but are less desirable because they are lower strength and harder to polish.

Overall, improving access to and understanding of food grade metals, particularly with respect to welding and polishing, will allow local manufacturers to produce additional equipment for the food processing industry, promoting both the small-scale industrial and manufacturing sector. This in turn will aid in overall country development and boost the national GDP.

If time and resources had permitted, we would have liked to try out additional designs such as a paddle or plow-type mixer for mixing of dry flour. We would have also liked to explore making equipment out of non-metal food grade sources, such as hand-turned bamboo agitators in plastic buckets, for use by very small, rural-based hammer mills.

ACKNOWLEDGMENTS

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### Table 2. Summary of results from vertical tank homogeneity tests

<table>
<thead>
<tr>
<th>Range (mg tartrazine/L)</th>
<th>0 RPM (no mixing)</th>
<th>200 RPM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard Deviation</td>
<td>15.0 – 184.2</td>
<td>118.2 – 122.7</td>
</tr>
<tr>
<td></td>
<td>459.0</td>
<td>1.61</td>
</tr>
</tbody>
</table>
Care Food Manuf.), Abiy Kasahun (QA Manager, Hilina Enriched Foods), Dr. Afeworke (MU, Dept. Health Sciences), Israel Hailu (MOH), Adamu Belay (EHNRI), Girma Mamo (MI), Yared Nega (MOI), Alem Abay (GAIN), and LemLem Flour Factory for detailed discussions concerning food fortification in Ethiopia.

REFERENCES


