Utilizing Mixed Methods Community-Based Participatory Research to Improve Environmental Health and Quality of Life Outcomes in Rural Rwanda

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Abstract

Background: Health risks associated with burning biomass and stress on forests caused by firewood demand have necessitated improved cookstove programs. This study aimed to introduce and assess the functionality and impact of an intervention rocket cookstove in a rural Rwandan village.

Method: This study used a mixed-method community-based participatory research (MMCBPR) design to introduce and test an intervention rocket cookstove. Interviews and focus groups were conducted to gather participants' perspectives on using stoves and their perceived impact on quality of life. This study occurred over five years and culminated in three distinct phases.

Results: Quantitative data showed that rocket stoves reduced firewood consumption by 30%–50% compared to traditional cooking methods. In addition, the qualitative data indicated widespread acceptance of the intervention concomitant with improved environmental health and quality of life outcomes. Participants reported improved health due to reduced smoke exposure, eye irritation, headaches, and an improved capacity for savings.

Conclusion: The longitudinal nature of this study provides insight into the complexities of MMCBPR in the Global South. The findings show that small interventions, such as an improved cookstove, can improve the quality of life of individuals in marginalized communities if researchers are willing to invest the time that MMCBPR requires. Suggestions for future studies, especially for researchers seeking to expand MMCBPR beyond the boundaries of public health in North America, are discussed.

Keywords: Community-based participatory research, mixed methods research, quality of life, sub-Saharan Africa, improved cookstoves.

Introduction

Rwanda has the highest population density in Africa, with an estimated 467 people per square kilometer (NISR, 2015; Thaxton, 2009). The population of 2022, projected from 2012 census data, was estimated to be approximately 13.697 million (NISR, 2015). More than 80% of the population depends on biomass (e.g., wood, animal dung, and plant matter) for energy production (NISR, 2016; Ndayambaje and Mohren, 2011). Biomass combustion and smoke inhalation have been repeatedly linked to health risks, including low birth weight, respiratory infections, cataracts,

malnutrition, and heart complications (Desai et al., 2004; Fullerton et al., 2008; WHO, 2010). The National Institute of Statistics of Rwanda (NISR) reported that acute respiratory infections were the leading cause of morbidity in 2014 and 2015, regardless of age, whereas pneumonia was the second leading cause of morbidity in children under 5 years of age (NISR, 2016).

Globally, three billion people depend on biomass for domestic energy (Gifford, 2010; Roden et al., 2006). Owing to the health risks associated with burning biomass and the stress on forests caused by firewood demand, improved cookstove programs have been initiated by international aid organizations, non-governmental organizations (NGOs), and governments (Gifford, 2010). Adkins et al. (2010) conducted field testing of various manufactured improved cookstoves in three sub-Saharan African countries. They argued that field testing the stoves with local cooks is essential to measure stove efficiency and local attitudes regarding using the stoves.

Study Purpose

Utilizing community-based participatory research (CBPR) paired with a complex mixed-method study design, an intervention rocket stove design was introduced and tested (Figure 1). The study participants were directly involved in modifying the stove design according to their needs and preferences and performed controlled cooking tests to assess the fuel efficiency of the stoves. Following the advice of Adkins et al. (2010), interviews and focus groups were conducted to gather participant perspectives on using the stoves and any perceived impact of the stoves on quality of life. Therefore, this study aimed to introduce and assess the functionality and impact of an intervention cookstove and contribute to the field of mixed-method CBPR, especially with respect to experimental studies conducted outside North America.

Study Rationale

The study site was a rural village in northwestern Rwanda, where most of the village residents were subsistence farmers and/or day laborers who reported routinely "sleeping without eating." Before 2009, many of these families had been hunters and gatherers for generations, with little to no agricultural experience. The collective knowledge of food cultivation and agroforestry in many farming communities in Rwanda was largely absent from this village. Although Rwandan policy prevents individuals from cutting wood on government land and encourages individuals to grow their own trees as a source of firewood (Mazimpaka, 2012; Ndayambaje, 2013), experts recommend a woodlot size of at least 0.75 hectares (Ndayambaje, 2013), well beyond the 0.25 hectares owned by most families in the study site.

Despite commercially available rocket stoves, this study investigated site-built rocket stoves constructed by

the study participants. The rationale for this choice is multi-faceted. Adkins et al. (2010) reported that the lifespan of tested manufactured rocket stoves ranged from 1 year to 5 years, with costs ranging from $10 to $22 (approximately 9000rwf – 20,000rwf). Most families in the study site would have difficulty purchasing a manufactured stove one time, much less replacing it every few years. Partnering with community members to build the stoves facilitated important CBPR principles, including relationship building, co-learning, and capacity building for the community members and researchers alike. In particular, the participants acquired the knowledge to build rocket stoves, which could potentially be a marketable skill.

At the time of this study, electricity was not available in the village, and there was no access to natural gas or propane. Village residents primarily depend on wood or charcoal for cooking on the traditional three-stone fire. Therefore, an intervention that reduces firewood consumption has the potential to positively impact the local environment and the quality of life of the participants. Due to the multiple phases and complex nature of the study, a complex mixed-methods community-based participatory research (MMCBPR) approach (Creswell, 2022) was the best option for obtaining the multiple types of data needed to best assess the intervention cookstove and its potential impact on participants' quality of life.

Community-Based Participatory Research

Community-based participatory research is grounded in researchers' commitment to conducting research with communities to bring about results that are meaningful to the people comprising said communities (DeJonckheere et al., 2019; Horowitz et al., 2009; Israel et al., 2013; Lucero et al., 2018). At its core, CBPR strives to reduce power imbalances by inviting community members to participate as co-researchers, not merely study subjects, to bring about positive change (DeJonckheere et al., 2019; Shalowitz et al., 2009). Diverging from post-positivist paradigms, practitioners of CBPR actively situate themselves within the research and invest significant time in developing collaborative, reciprocal partnerships between researchers and community members.

CBPR has gained popularity as a research approach in various fields, especially in public health (DeJonckheere et al., 2019; Israel et al., 2013). Israel et al. (2013) investigated the social determinants of health and provided nine guiding principles for CBPR. While acknowledging that all nine principles are not relevant for every project, the tenets of partnership building, trust development, and

collaborative study design are at the heart of every CBPR study.

Intersection of Mixed Methods Research and CBPR

Combining CBPR with mixed methods is an example of an advanced application of mixed-methods research (Plano Clark and Ivankova, 2016). The overarching goal of MMCBPR is to empower researchers and community partners to elucidate and make use of metainferences, which are only available through the integration of quantitative and qualitative datasets, to create positive change within a community (DeJonckheere et al., 2019; Lucero et al., 2018). Windsor (2013) pointed out the additional advantages of MMCBPR, including combining prolonged community interaction with the depth of qualitative and quantitative research. Israel et al. (2013) and Lucero et al. (2018) have stressed the importance of developing trust between researchers and community members for effective and equitable research. Researchers must be willing to put in time and effort to build trust and recognize that levels of trust change over time as community partnerships develop.

The remainder of this manuscript explores a multi-year, multi-phase MMCBPR project situated in rural northwest Rwanda (Figure 1). Partnership formation, the complex MMCBPR design process, methods of integration, study results, and implications drawn through metainferences will be thoroughly explored.

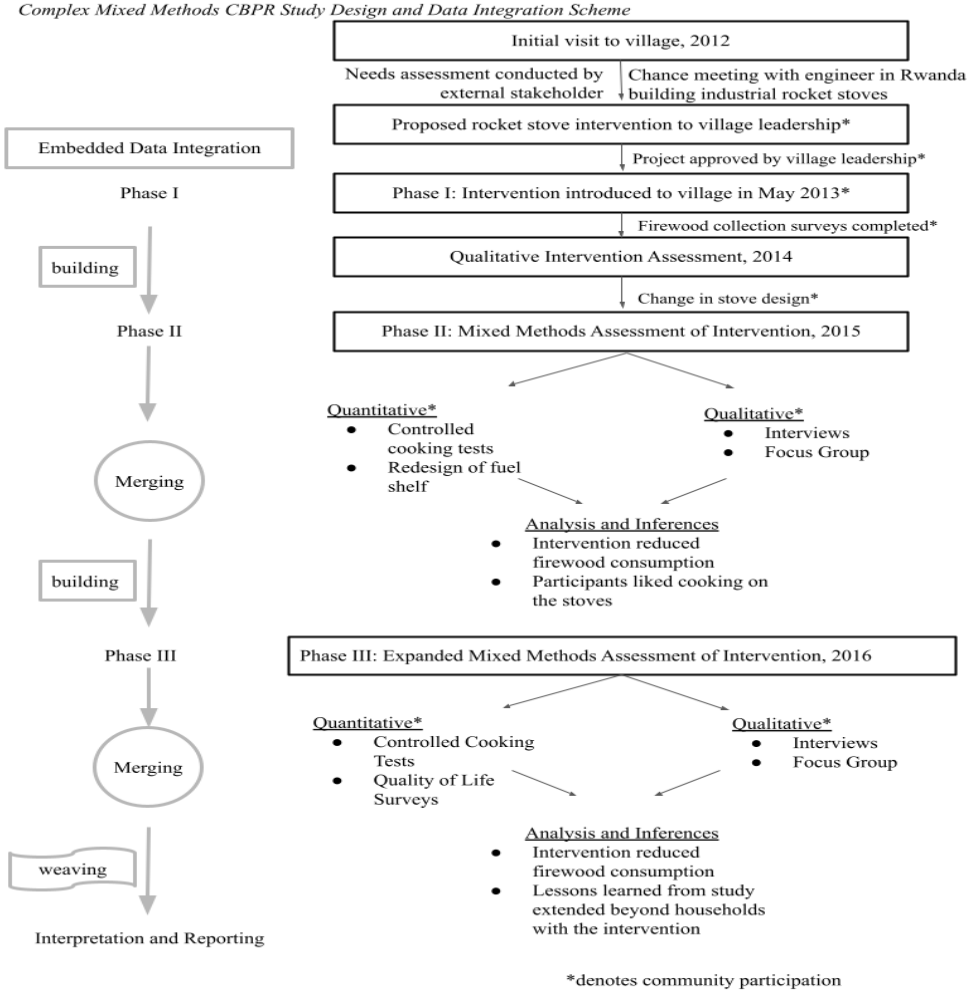
Study Design

This study occurred over five years and culminated in three distinct phases as seen in Figure 1.

Each phase was built on the previous phase, and data collection and interpretation were connected over the

Figure 1

Complex Mixed Methods CBPR Study Design and Data Integration Scheme



course of the study by consistency in the study participants, location, and overall goals. The comprehensive datasets from the study were made possible due to investment in partnership development, establishing researcher-participant trust, and a commitment to the project over a long period, all of which are core principles of CBPR.

Partnership Development

This study was conducted in a rural village in Rwanda's western province near the border with the Democratic Republic of the Congo. The Rwandan government established the village in 2009 as individuals living in and around the Gishwati Forest were removed and relocated. Upon relocation, each family received a wooden house built by the

government and a 0.25-hectare plot of land to farm.

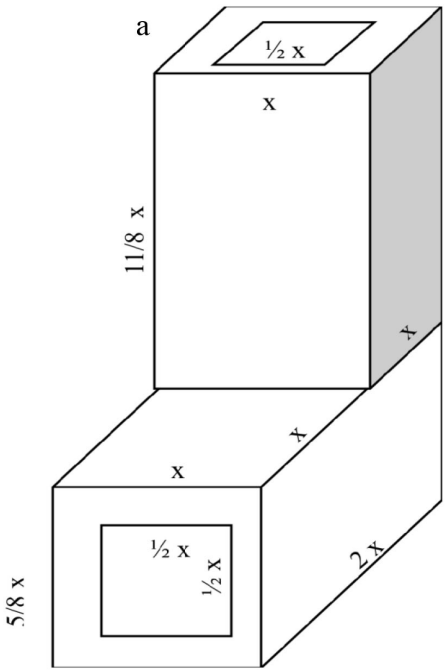
Phase I

Our first introduction to the community came during a university-sponsored study-abroad program in 2012. Three Rwandan international students at our American university participated in the study-abroad program. They were shocked by the poverty and living conditions in the village. They provided some additional context for the Americans in the group, including the fact that most of the cooking in the village was conducted outside over open three-stone fires (see Figure 2). We also learned that the village was built on the site of a former forest that had been cut down to build the village to house the people from the government relocation program, meaning that the only energy source available to the village was in short supply (Official Gazette, 2010).

This brief visit to the village and a chance encounter with an American engineer in Rwanda building industrial rocket stoves for an orphanage planted the seed for the multiphase, multiyear project shown in Figure 1. The desire to work with the village community to improve their quality of life led to working with their village representatives. A village needs assessment was shared with us, and one need was improved access to energy sources. After conversations with the village representative, we proposed introducing the rocket stove intervention upon our return to Rwanda in 2013. The village leadership approved the project, and with the aid of the engineer, the faculty and students learned to build rocket stoves and developed a manual with photos of each step that included written directions in both English and Kinyarwanda.

The faculty and students returned to continue with the project in 2013. The project was collaboratively designed such that three building teams composed of students and community members, both men and women, built six rocket stoves at sites in the village selected by village leadership. These stoves were approximately 64 cm deep and 79 cm tall, with a 20 × 20 cm fuel compartment and chimney (Figure 2).

Figure 2



b

Note. Figure 2a shows the basic diagram and ratios for the rocket stoves built at the study site. Figure 2b shows a three-stone fire (left) and rocket stove (right) during one of the controlled cooking tests during Phase III of the study.

The student-community member teams were critical to the MMCBPR design and aligned with several of the guiding principles espoused by Israel et al. (2013), including "CBPR builds on strengths and resources within the community" and "CBPR fosters co-learning and capacity building among all partners" (p. 9-10). While the students understood the steps for building stoves and the desired dimensions, the skills of the community members were quickly evident. Despite the language barrier, observing the blended teams find ways to communicate and collaborate to build six stoves with perfect edges and corners was indeed rewarding.

Because most of the people living in the village were subsistence farmers and/or day laborers, they were compensated for their time building stoves at a rate agreed upon by the village leadership and village representative. Due to the subsistence nature of life in the village and the necessity of finding small jobs each day to earn money for food, the study participants could not be expected to volunteer their time. According to the village leadership, on a good day, individuals might earn 5000 Rwandan francs (rwf), which was approximately 3 USD based on the exchange rate at the time. Hence, we paid each participant 5000 rwf at the end of each day.

We returned in 2014 for the third consecutive study abroad program, demonstrating a commitment to another guiding principle of CBPR, "CBPR involves a long-term process and a commitment to sustainability" (Israel et al., 2013, p. 11). Community members remarked that we were the first group to return to the village for multiple visits. This commitment to return year after year furthered our relationship-building and increased trust between the community and researchers. Upon returning to the village, we planned to gather qualitative information about the rocket stove owners' opinions on the stoves. We were disappointed to learn that only one stove was still in use. From the interviews, we learned that we

had committed a grave mistake with respect to CBPR: we did not involve the community in the original design of the stoves, relying instead on the dimensions and design provided by the engineer. The stoves were too tall and used too much wood, precisely the opposite of the desired results. While building the initial stoves was supported by the community, we failed to consider how the community was most used to cooking, crouched over a three-stone fire. Through follow-up interviews, the participants expressed their commitment to the idea of improved cookstoves and their desire to modify the dimensions to build stoves that better met the cultural and physical needs of the participants (Horton, 2017).

Phase II and Phase III

One researcher returned to the village in 2015 and 2016 to test the efficiency and acceptance of the smaller stoves and to investigate the quality of life of village residents. Over the five years of the project, the participants remained constant. By 2016, the study participants no longer asked to be paid at the end of each day's work and chose to wait until the end of that study phase to receive a larger sum of money at one time. This change in behavior demonstrated a shift in trust between the researcher and community members. The relationship had developed over time that the community members trusted the researcher to keep their word and pay the agreed-upon wages at the completion of the study.

Complex Mixed-Method CBPR Design

The mixed-method portion of the study began in 2015 (Figure 1) and culminated in a complex design comprising two convergent designs (Creswell, 2022), both of which incorporated CBPR.

Phase II

During Phase II, six stoves were constructed, 36 cm deep and 46 cm tall, with a fuel chamber and chimney 12 cm square, based on the dimensions suggested by community members during the 2014 assessment. The original fuel shelves used with smaller stoves were 36 cm deep and 2 cm tall. Pilot testing of these stoves indicated no significant difference in fuel efficiency between the rocket stoves and the three-stone fires. After brainstorming with the participants, we chose to alter the fuel shelf to a height of 8cm, leave several centimeters of space between the shelf and the back wall so that coals and ashes would fall to the bottom of the fuel chamber, and use an ash puller to remove ashes that were impeding the airflow through the stove. After these modifications, the rocket stove reduced fuel consumption by 50.2% compared to the three-stone fires (Horton, 2017).

Nine study participants enrolled in Phase II participated in a 25-question semi-structured interview designed to gain information regarding the overall quality of life within the village. A

translator fluent in English and Kinyarwanda was employed and all interviews were recorded.

After completion of the stove testing, a focus group was conducted. Participants were asked about their experiences of using the stoves and whether they recommended continuing with the rocket stove intervention. Because the participants performed the stove tests and weighed the firewood before and after the tests, they knew that the rocket stove used less wood than the three-stone fire. This knowledge, combined with their positive experiences in using the stoves, resulted in the approval of Phase III.

Phase III

In Phase III, the scale of the study was expanded for both quantitative and qualitative analyses. Twenty individuals, both men and women, were enrolled in the controlled cooking tests, ten of whom had rocket stoves constructed in their homes in outdoor kitchens. The village leaders employed purposeful sampling (Creswell & Plano Clark, 2018) to select the participants. The study design necessitated that at least one person at each cooking site could read and write. Additionally, individuals who could commit to all seven days of stove testing were chosen to maintain consistency and reduce variability.

Interviews were conducted with participants who had rocket stoves at their homes to investigate their attitudes regarding the stoves' use and positive or negative impact. Nine participants from Phase II were interviewed again to gain insight into how their lives had changed over the last year. Some questions, such as "What do you consider to be the basic needs for your family?" and "What do you believe is necessary to be able to live a good life in your village?" were asked both years in order to discern any changes in participant perspectives, needs, and capabilities.

After completing the controlled cooking tests, participants met at a central location to discuss the controlled cooking tests and their opinions regarding the rocket stoves, life in the village, and general quality of life. Ten open-ended questions were used to direct the conversations during the focus group. The focus group used the same translator, lasted approximately one hour, and was recorded for further analysis.

Experimental Design: Controlled Cooking Tests.

To assess and compare the efficiency of the rocket stoves to the three-stone fires, a total of 70 controlled cooking tests, seven at each of the ten sites, were conducted. One test is defined as cooking the same amount of food simultaneously on the three-stone fire (control group) and the rocket stove (variable group) (Adkins et al., 2010). Firewood, *Eucalyptus spp.,* was purchased in bulk from a supplier in a neighboring village. Each day, 20 bundles of wood were prepared and

the starting mass was obtained. With input from the participants, mixed brown beans, approximately the size of navy beans, from the most recent growing season, were chosen as the test food. The rationale for cooking beans was that beans take longer to cook than other commonly cooked foods such as potatoes and would therefore be a better indicator of the efficiency of the stoves. Each day, two kilograms of beans were cooked on a three-stone fire and rocket stove. To further reduce variability, 4L of water was added to each identical, 6L-capacity aluminum cooking pot at the start of each trial. An additional 2L of water was added approximately halfway through cooking. After cooking, the mass of the remaining wood was recorded.

Data from controlled cooking tests were analyzed using the Statistical Package for the Social Sciences (SPSS). Analysis of variance (ANOVA) was performed to determine whether any statistically significant differences existed in firewood consumption. To further investigate potential differences in wood consumption at different sites throughout the seven trials, repeated measures ANOVA with Tukey posthoc analysis was performed.

Prior to starting data collection, with the help of the Phase II participants, the Phase III participants were trained to conduct the cooking tests. To improve reliability and minimize confusion, we conducted a practice run in which we split the participants into two groups and conducted a controlled cooking test, as described above, to ensure that each participant understood the procedures and expectations.

From the project's inception in 2013, the village participants always included both men and women on the stove-building teams, the cooking-test teams, interviews, and focus groups. Based on what we thought we understood about gender norms in Rwanda, we were initially surprised that women participated in the stove building and men participated in the cooking tests. However, over the multiple years of the project, we observed somewhat less rigid gender norms in the village. For example, it was common to see men, women, and children carrying water from the village spigots, women caring for livestock, or men processing clay and molding pots. Investigating these relaxed gender norms would make an interesting future qualitative study.

Study Results

Phase II was essentially a pilot study to gain insight into how participants spoke about their quality of life and whether the stove intervention project was worth pursuing in the community. During this phase, the community members spoke about the challenges they faced in the village related to finding employment and having enough money to buy food to feed themselves and their children. Moreover, the challenge of having enough money to pay school fees for their children and growing crops on

rocky ground in the volcanic region of northwestern Rwanda is a struggle.

During the testing of the smaller rocket stove, an experimental modification was made with respect to the fuel shelf (discussed previously). This modification was made collaboratively when, after two days of testing, it was clear that the rocket stove did not use less wood than the three-stone stove. MMCBPR provides built-in flexibility so that the researcher and community members can discuss the experimental design and make adjustments to determine if the outcomes could be improved. After modifying the fuel shelf, the rocket stoves used significantly less firewood. At the completion of stove testing, community members and the researcher discussed the results and their attitudes regarding using the stove—a period of active data integration. While the original study aimed to determine if the stove used less firewood, the community members discussed additional benefits to using the stove: "it [rocket stove] does not make the cooking pot dirty and the smoke is less", "the fire does not get taken away by the wind", and "another advantage of the rocket stove is it cooks faster."

Phase III

For Phase III of the project, an additional seven rocket stoves were built at sites determined by the village leadership. Participants at each site performed seven controlled cooking tests on their rocket stove and a three-stone fire. As the controlled cooking tests were conducted, the researcher conducted interviews at each site.

Controlled cooking tests. Controlled cooking tests were conducted at ten different sites, with seven replications at each location. When the data were pooled across all sites and trials, the site-built rocket stoves reduced wood consumption by 32.74% ($F = 27.90$ ($df = 1$, $p \leq 0.001$)). For each trial, the rocket stoves consistently performed better than the three-stone fires with respect to wood consumption; in some cases, consumption was reduced by as much as 51.17%. Furthermore, over time, wood consumption for both the three-stone fires and the rocket stoves showed a decreasing trend, with average wood consumption plateauing at 4.19 kg for three-stone fires and 2.42 kg for rocket stoves. There were no statistically significant differences in wood consumption among sites.

Participants' attitudes regarding the use of the site-built rocket stoves. In addition to the benefits discussed above from Phase II, the participants also pointed out that the rocket stove was safer than the three-stone fire and would reduce children getting burned, as most mothers have their children with them while cooking (see Figure 3).

Reducing the size of stoves increased acceptance. Participant B. said, "*Why would we go back to a three-stone fire when the rocket stove is so nice*?" SK, a middle-aged man in the focus group, said, "*For me, what I learned on the*

rocket stove, the first thing I saw was the benefit of reducing the firewood and cooking faster…and it is a clean way of cooking in a house…" Those same sentiments, especially reducing firewood consumption and cooking time, were mentioned many times by different participants throughout the focus group. Participants were explicitly asked if there was anything they did not like about the stove and the response was, "*No, nothing*."

Discussion

This study utilized community-based participatory research (CBPR) paired with a complex mixed-method study design to introduce and test an intervention rocket stove. The merging of the quantitative and qualitative datasets yielded compelling evidence that the rocket stoves were more efficient and used less wood than the traditional three-stone fires and that the study participants viewed the stoves positively and expressed intentions to continue using the stoves after the completion of the study.

The lessons learned from this study are not limited to those gleaned from examining the quantitative and qualitative datasets individually. Additional lessons emerged from merging the data and mining the results across the datasets for further insights, or what Creswell (2022) refers to as metainferences (Figure 3). In this study, three categories of metainferences emerged: additional benefits of the rocket stoves beyond reducing firewood consumption, applying the lessons learned from cooking on the rocket stoves to cooking on the three-stone fires, and the long term projected benefits from the continued implementation of the firewood reduction strategies for both the rocket stoves and the three-stone fires.

Additional Benefits of the Rocket Stoves Beyond Reducing Firewood Consumption

In particular, the women noted that cooking on a rocket stove is easier and requires less tending, especially when it is windy. With three-stone fires, the wind interferes with the fire, making the cooking process take longer. They also stated that even after the fire is out, the rocket stove stays hot longer, enabling them to cook additional food on top of the stove, keep the food warm, or use the hot coals for cooking other food, such as roasting potatoes. For example, participant B., a woman in her late thirties, said, "*What it helps me [with] is that after you have cooked the first [food], you don't need to add more firewood and you can cook whatever it is you want on it without adding more… that is its advantage*." Several other participants also noted that the cooking methods used during the study saved water, money, and firewood. Participant Bj. explained,

> For these ones who have the rocket stoves it means that if they were spending 1000 [rwf] on firewood now they will be spending 300. The 700 [rwf] that is remaining

> will be their benefit because they have a way to save it.

Phase II participants who had been using rocket stoves for one year by the time of Phase III shared other ways the rocket stoves had benefited them and their overall quality of life. Two of the participants stated that they saved money they otherwise would have spent on firewood to buy a pig. B. said, "*When it [the sow] is in heat we go and find where they have a nice male pig and we pay 5000 [rwf] so their male pig will inseminate our pig. After I get the piglets, I put all of them on sale so that I can get money to buy other things.*"

Smoke reduction from cooking on the rocket stoves was another common theme. B. said, "*...when you light fire on it [rocket stove] there is no smoke and you can make the fire without crying at the same time, so you make fire and cook nicely without crying or sniffing.*" *A. said that cooking on a rocket stove is easier than cooking on a three-stone fire. "You see the challenge of cooking on [a] three-stone fire, by the time the food is cooked your eyes are red because of smoke or with a headache.*"

Applying the Lessons Learned from the Rocket Stoves to the Three-Stone Fires

As noted previously, wood consumption for three-stone fires decreased over the course of the study. The participants were asked if they could explain this observation. Participant T., an unmarried man in his mid-twenties who helps to care for his parents and does much of the cooking, noted,

> …on the traditional three-stone fires we were putting a lot of firewood. We were putting five to six sticks of firewood and the fire would go on the sides of the cooking pot. We thought that that fire is also being useful but then we found out that the fire [that] goes on the sides of the pot is wasted.

M. went on to explain,

> …a lesson we got as we were using the rocket stove: we saw that it was using less firewood so we said what if we were to reduce the size of the firewood on the three stone fire as well and see how much it can consume? That is how we manage to reduce the fire in the three-stone fire and that's how the amount we were using in the beginning is different to the amount at the end.

Projected Benefits from Continued Use of Firewood Reduction Strategies

One of the major findings of this study was that site-built rocket stoves reduced firewood consumption by 30% to 50% when compared to traditional three-stone fires (Figure 3). The experimental data presented here were based on cooking two kilograms of mixed brown beans, however, beans are not cooked for every meal. However, based on surveys collected in 2013 (Horton,

2017), families at the study site typically eat two meals per day, and beans are among the most common foods eaten in the village.

Based on the controlled cooking test data, we extrapolated the amount of wood and money savings that would occur over the course of a year (Table 1). The figures shown in Table 1 are a conservative estimate because the calculations were based on cooking three meals of beans in one week but did not account for wood savings from the remaining eleven meals per week. Due to the three-stone fire users recognizing that using less firewood was possible and beneficial, even families without rocket stoves could experience money and firewood savings due to learning a more efficient way of cooking on the three-stone fires.

Table 1

One-Year Projected Firewood Cost and Consumption Pre- and Post-Intervention

Projected wood cost (rwf) and wood consumption (kg)	One Family	Ten Families	900 Families*
Three-stone fire pre-intervention			
Wood cost	36,051 rwf	360,510 rwf	32,445,900 rwf
Wood consumption	955.50 kg	9,550 kg	859,950 kg
Three-stone fire post-intervention			
Wood cost	24,661 rwf **(+ 11,387 rwf)**	246,610 rwf **(+113,900 rwf)**	22,194,900 rwf **(+10,248,300 rwf)**
Wood consumption	653.64 kg **(+301.86 kg)**	6536 kg **(+3,014 kg)**	588,276 kg **(+271,674 kg)**
Rocket stove			
Wood cost	14,243 rwf **(+21,817 rwf)**	142,430 rwf **(+218,080 rwf)**	12,818,700 **(+19,637,200 rwf)**
Wood consumption	377.52 kg **(+577.98 kg)**	3775 kg **(+5,775 kg)**	339,768 kg **(+520,182 kg)**

Note. *Approximate number of families in the village. Bolded numbers indicated projected savings in wood and Rwandan francs based on cooking three meals of beans/week.

According to the estimates in Table 1 and the cost of one bundle of firewood, the rocket stove would save a family approximately 20,000 rwf per year (approximately 22 USD). Although this figure may seem inconsequential, it covers the 12,000 rwf cost of yearly health insurance for a family of four in the first and second Ubudehe categories of the national community-based health insurance scheme (*Official Gazette, 2015; Official Gazette,* 2020; *Understanding Social Security*, 2018).

The need to purchase mandatory health insurance weighed heavily on the participants during the interviews, with 80% mentioning the challenges of purchasing insurance. Participant M. talked about how the government could penalize them if they could not show proof of insurance.

> *"The first thing for us to have a good life is getting health insurance. You see that the month is ending. That means that the leaders have started to attack us... they would come and take my pig for example."*

He said that he could only get his pig back after paying for health insurance and showing proof. If he could not do so, the government would sell his pig at less than the insurance cost. None of the participants specifically stated they would use the money saved on purchasing firewood to purchase health insurance (most of them mentioned more immediate needs like purchasing food); however, the projections shown here indicate that is one possible use of the savings.

Study Limitations

Conducting a multi-year, multi-phase complex MMCBPR study in the so-called developing world, when the researchers do not speak the language of the participants, is challenging. Because of the inherent flexibility of complex MMCBPR, especially when paired with pragmatism, researchers and community members can decide how best to meet these challenges (Lucero et al., 2018).

One challenge during this study centered around clear communication of expectations and intent. Despite conducting practice runs of the controlled cooking tests, at least one group misunderstood the importance of using the three-stone fire as the control group. Instead, they used a different stove for two of the control trials. Therefore, those two trials were excluded from the final dataset. On each day of testing, the translator and researcher made multiple visits to each test site to inspect the participants' methods for consistency and to explain the procedures and expectations. However, we could not be at each site for the entirety of the trial, and the sites were spread throughout the village. This particular challenge demonstrates

an important tradeoff with respect to CBPR: the researcher could have insisted that the testing sites should be closer together for ease of observation. But that could have damaged the trust between the researcher and the community and limited the village leadership's authority to choose the stove sites based on the needs of the people within the village. In this case, the researcher chose to prioritize the relationships that had been developed over the previous years. Thus, respect for the authority of the village leaders and avoiding damaging the trust relationship between the researcher and the community was important.

An additional complication, from an experimental design perspective was that the study participants altered the way they cooked over the three-stone fires during the testing period. Since the three-stone fires were the control group, changes made while the experiments were conducted were not ideal. However, this change turned out to be fortuitous because it led to one of the most critical metainferences from the study: the strategies learned from cooking with the rocket stoves could be applied to the three-stone fires, resulting in reduced firewood consumption and the concomitant money savings.

Implications for Future Studies

The study participants reported multiple times that more people in the village wanted the rocket stoves because they had seen and heard about the benefits. There are now multiple people in the village who know how to build rocket stoves; they only lack materials. One future goal is to obtain funding to purchase a rock crusher and a brick press so that village residents can use the abundant volcanic rock to make their own bricks. Rocket stove interventions have been shown to save a considerable amount of firewood. If more people in the village had access to the stoves, the benefit to the local environment would be even more substantial.

Additionally, the potential health benefits of introducing the rocket stoves must be assessed. Several participants noted that using rocket stoves reduced eye irritation and coughing. Measuring the differences in smoke exposure between the three-stone fires and rocket stoves would give insight into the respiratory disease burden of the study participants and the billions of individuals globally who depend on biomass as an energy source for cooking and heating. Continuing to employ MMCBPR will be essential to fully understand the impact of the rocket stove intervention on the potential health and quality of life benefits for the study participants.

Conclusion

This study aimed to introduce and assess the functionality and impact of an intervention cookstove and contribute to the field of mixed-methods CBPR, especially with respect to experimental studies conducted outside of North America. For five years, relationships

were developed with participants at the study site, which facilitated the completion of the study. Qualitative data gathered during interviews and focus groups indicated participant support due to overwhelming positive feedback regarding the use of rocket stoves. Rocket stove users reported improved environmental health outcomes owing to reduced smoke exposure, thus reducing eye irritation and headaches. Even participants who did not have a rocket stove at their homes voiced support for the project because of the unanticipated benefit of reducing wood consumption in three-stone fires.

The quantitative data are also clear – the rocket stoves reduced firewood consumption by 30%–50%. However, the developing world is littered with examples of projects whose data were promising but ultimately failed in the field (Maier et al., 2016). Why should this rocket stove project be any different?

Ultimately, the difference lies in study design and implementation. From its inception, this work was intended to be participatory with open dialogue and collaboration between the researchers and the participants (Horowitz et al., 2009; Minkler et al., 2008; Shalowitz et al., 2009; Wallerstein & Duran, 2010). We did not visit the village and, based on our outsiders' perspective, decided what would benefit the people. We met them where they were, listened to their priorities and concerns, and collaboratively designed the project.

Despite having buy-in from the village leaders and residents, there was no guarantee the people would like or find value in using the stoves. The only way to answer those questions was through a complex, mixed-method, community-based participatory approach (Creswell, 2022). Because of the mixed methods nature of this study, we were able to identify, through interviews and focus groups, what the improvement in stove efficiency meant for the lives of the people using them, whether they would use the stoves after the conclusion of the study and identify positive lessons beyond the intended scope of the project. As of the last visit to the village in 2019, the rocket stoves are still regularly used, and additional stoves will be built during the 2023 village visit.

The data presented here show that small interventions, such as an improved cookstove, can improve the quality of life of individuals in marginalized communities if researchers are willing to invest the time that CBPR requires. Relationships and trust-building efforts cannot be rushed and are essential for reducing power distances to establish authentic reciprocity throughout the research process. Hopefully, this article will raise the profile of complex MMCBPR beyond the traditional borders of public health and North America to include complex questions related to the quality of life, climate

change, education, etc., throughout the world, especially in the Global South.

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Notes

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Figure 3. *Joint Display of Data Integration for Rocket Stove Intervention Across all Study Phases*

Study Phase	Quantitative Data	Qualitative Data	Inferences
Phase I	N/A	Stoves built were not being used because they were too tall and used too much wood.	Researchers realized they had not taken community habits and preferences into account or involved the community in the original design of the stoves. This oversight was corrected in Phase II.
Phase II	Three controlled cooking tests were performed after modification of the fuel shelf. Results indicated the rocket stoves reduced wood consumption by 50.2% compared to the three-stone fire.	Focus group data show participants found benefits to using the stoves: • "the smoke is less" • "the rocket stove cooks faster" • "it [rocket stove] consumes less firewood	Study benefits extend beyond reduced firewood consumption: • "it [rocket stove] will save the money we were using on firewood and steel wire [and that money] can be used to feed the family and other things" • "[we can] use the money to buy food like beans and Irish potatoes"

Figure 3 (continued)

Study Phase	**Quantitative Data**	**Qualitative Data**	**Inferences**
Phase III	Seven controlled cooking tests were performed at each of ten sites, for a total of 70 tests. • ANOVA showed significant differences between the two cooking methods. Rocket stoves reduced wood consumption by 32.74%. • Firewood consumption for both the rocket stoves and three-stone fires decreased over the first three trials before plateauing.	In addition to the benefits shown from Phase II, Phase III participants also said: • "it [rocket stove] is a clean way of cooking" • " we saw the way of measuring water, it means even if you were to cook 3 kg [of beans] you could use the same ratios that you saw and will know how much water you should start with and how much water you should add. So instead of using a lot of water we will save water too since we have learnt the right ratios" Phase II participants who had the stoves for a year had additional insights: • "it cooks the food nicely because the fire is constant and the food won't smell of the smoke because you see on the three stone fire a lot of smoke goes to the food...and because of the smoke you find the food has changed its color but on that one [rocket stove] it can't change the color because the smoke does not go up • "I managed to... save the money and I bought a pig"	Study benefits extend to households who not yet have a rocket stove: • "on the traditional three stones fire we were putting a lot of firewood we were putting five to six sticks of firewood and the fire would go on the sides of the cooking pot and we thought that that fire is also being useful but then we found out that the fire that goes on the sides of the post is wasted" • "we were using the rocket stove we saw that it was using less firewood so we said what if we were to reduce the size of the firewood on the three stones fire as well and see how much it can consume and that is how we manage to reduce the fire in the three stones fire"